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REVIEW OF THE PHYSICAL OCEANOGRAPHY OF MASSACHUSETTS BAY

By

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Woods Hole, Massachusetts 02543

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TECHNICAL REPORT

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Approved for Distribution Ferris Webster

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Department of Physical Oceanography

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Introduction

This report responds to an invitation of the National Marine Fisheries Service, Northeast Fisheries Center, dated 18 December 1972 (subsequently formalized by a proposal and NMFS Contract #03-3-043-40 with the Woods Hole Oceanographic Institution), in which the author was asked to report on the present knowledge of oceanography of Massachusetts Bay and vicinity. We have attempted herein to describe the temperature-salinity cycle and the current system and to provide a comprehensive annotated bibliography on hydrography, chemistry and sea level for Massachusetts Bay.

Except for the recent efforts by faculty and students in the Departments of Civil Engineering and Meteorology at the Massachusetts Institute of Technology, and several other groups under the aborted NOMES program, no concerted effort to study Massachusetts Bay, per se, or parts thereof, has been undertaken. There is on file in Woods Hole a modest body of temperature information resulting from occasional stations representing parts of programs encompassing the Gulf of Maine since 1912, or bathythermograph profiles of research vessels in transit through the area since the 1940s. Some of the bathythermograph data are accompanied by surface salinities. Station data, including both temperature and salinity, are virtually worthless as they are so few and scattered in space and time. In addition to the irregular traverses of research vessels across Massachusetts Bay, regular daily observations of temperature and salinity (surface and bottom) have been obtained from Boston Lightship since 1956. From this patchwork of data a description of the temperature-salinity cyles has been developed.

As will be seen in Table I, current measurements have been made from time to time and place to place since 1855, to the point where there is a general predictive capability with regard to the tidal oscillation. Most of the emphasis on tidal currents has been directed at Boston Harbor and approaches. In recent years, 1971 and 1972, self-recording current meters have been employed at ever greater distances from the channels entering Boston Harbor and at several levels at each station. These data are still in the data reduction and analysis phase. We must patiently await the reporting of this information. These data should be of the quality such that hourly velocities for each station and level can be predicted and net daily and average monthly displacements (residual drift) determined.

Should these as yet unreported current measurements provide the desired objectives, they will supplant the conjectures about residual drift presently based on drift bottle and seabed drifter data.

Thus to summarize we can describe the annual temperature-salinity cycle with a fair degree of certainty, we have a general understanding of the advance and retreat of the tidal oscillation and of the residual drift.

The cause of an indraft of cold-saline water at the bottom at Boston Lightship during late spring and summer is not documented, nor is how widespread the phenomenon. The M.I.T. investigators have some concepts about an eddy system in the offing of Boston which they were hard at work on during early 1973. They have also observed and discussed some long-term non-linear internal waves associated with the tidal oscillation across Stellwagen Bank during the period of the year when the thermocline is well developed.

The text of this report has been written in an attempt to summarize our knowledge, either from studying the original data or including the interpretations of those who have written about the area. The reader is encouraged to study the bibliography for details which the author has failed to include in this report. We hope the annotations help one to select those most germane to his needs.

Massachusetts Bay lies on the west side of the Gulf of Maine in the vicinity of 40°N, 70°W. It is bounded on the north by Cape Ann, on the west by the eastern coast of Massachusetts, centered on Boston, on the south by Cape Cod Bay and Cape Cod. Land encloses 75% of the perimeter of the combined Massachusetts and Cape Cod Bays. The chief topographic feature is the submarine ridge which rises to within 20 meters of the sea surface on the east side of the Bay between Cape Ann and Cape Cod. Two channels, one south of Cape Ann (60 m) and one north of Cape Cod (60 m grading to 40 m) separate Stellwagen Bank from the mainland. This submarine ridge blocks the free exchange of water at depth with the Gulf of Maine and is important in triggering the internal waves in the seasonal thermocline. The water deepens west of Stellwagen Bank to Stellwagen Basin, ca. 80 m or more, then gently rises toward the coast. East of Boston and Plymouth the bottom is hummocky and rough, whereas it is generally smooth in Cape Cod Bay, Stellwagen Basin and on Stellwagen Bank.

Annual cycle of temperature and salinity in Massachusetts Bay

The annual cycle of temperature and salinity as described herein is based on the extensive file of temperature, salinity, depth data on file at the Woods Hole Oceanographic Institution.

We have searched for typical temperature sections across major portions of Massachusetts and Cape Cod Bays (Figs. 1-12) and have drawn temperature depth profiles along those sections.

During January the temperature is approaching a minimum, with temperatures ranging from 1 to 6°C. The colder temperatures occur in Cape Cod Bay, the warmer east of Stellwagen Bank. No vertical stratification occurs in the upper 40 m. Minor stratification, $< 1°C$, occurs below that level.

The temperature minimum, 0 to 3°C, is reached in February with the lowest temperature occurring in Cape Cod Bay. The water is virtually isothermal vertically, the gradient being $< 1°C$.

By March vernal warming has commenced with temperature ranging from 2 to 5°C. As before the colder temperatures are found in Cape Cod Bay and the warmer ones east of Stellwagen Bank. Vertical temperature gradients are $< 1°C$.

Vernal warming progresses in April to the stage where a vertical temperature gradient of nearly 2°C is apparent over most of Massachusetts Bay. Surface temperature ranges from 4 to 6°C whereas bottom temperature is restricted to 2 - 4°C. Warmest temperatures occur in the shallow parts of Cape Cod Bay and the coldest near the bottom on the east side of Stellwagen Bank.

By May the bottom temperature has warmed very little, to $< 4°C$ except in the shallow parts of Cape Cod Bay where it reaches 10°C. On the other hand surface temperature has risen to $> 9°C$ for the most part, reaching 12°C in isolated patches. The diffuse vertical gradient is restricted to the upper 30 m.

In June the deeper parts of Massachusetts Bay are still $< 4°C$. Temperatures in the vicinity of 40 m may approach 8°C, or even 11°C on the east side of Cape Cod Bay. Surface temperature ranges between 13 and 17°C. The vertical temperature gradient is chiefly confined to the upper 40 m.

Bottom temperature continues with little change into July. Surface temperature east of Boston and over Stellwagen Bank approaches 15°C, whereas over Cape Cod Bay it approaches 19°C and east of the southern part of Stellwagen Bank it reaches 23°C. The thermocline of several degrees per meter centered about 10 meters lies below a much weaker gradient.

By August the bottom temperature is still isolated from the annual warming cycle. Bottom temperatures below 40 m remain well below 10°C. Surface temperature approaches 20°C. The mixed surface layer has deepened to below 10 meters over much of the area and the thermocline has been pressed down to between 15 and 25 meters.

Surface temperature commences to cool appreciably in September, ranging from 12 - 16°C throughout Massachusetts and Cape Cod Bays. Bottom temperature continues to approximate 6°C in the deeper parts. The thermocline continues to deepen, centered near 20 meters and continues to become more diffuse.

By October the surface temperature is reduced to about 14°C and the deep bottom temperature has increased a degree or so to 7 - 8°C as the thermocline becomes more diffuse and deepens. The mixed surface layer may extend from the surface to 10 - 20 meters.

The autumn overturn is in full force during November. The water is virtually isothermal with depth at 8 to 11°C.

During December the overturn continues as the whole water column cools to about 7°C.

The annual cycle of temperature is also demonstrated in the Temperature-Time-Depth profiles for Boston Lightship from 1956-1970. Figures 15 to 29 represent the temperature cycle for the individual years, whereas figures 13 and 14 provide an average for the 15 years.

The whole water column is thoroughly mixed until the end of March when a very weak vertical gradient commences as the surface begins to warm. This heat is mixed downward quite effectively to about 15 meters through May following which the thermocline strengthens between 5 and 15 meters through August. In the meantime the bottom waters are warming very slowly at a rate of about 1°C per month. Maximum surface temperature is reached in August. Very slight cooling occurs in September. During this month heat is mixed downward so that the strongest part of the thermocline is centered about 15 m, and the maximum bottom temperature is achieved at the end of September. Temperature drops rapidly during October so that by early November the whole water column is isothermal again and is chilling at a rate of about 3°C per month.

The diagrams for the individual years (Figs. 15 - 20) are not as smooth and regular as the average for the 15 years. They suggest, in addition to the cycle outlined above, secular differences from year to year as to the maximum or minimum temperatures reached, the times of maximum or minimum, the effect of irregular upwellings of cold water which penetrate the underside of the thermocline in July and August.

The data on the distribution of salinity in Massachusetts Bay is minimal. Except for Boston Lightship surface salinity data is available for only March, April, May, June, September, October and December. Much less data is available at depth.

The salinity at the surface ranges between 30 and 33‰ with the minimum occurring in May and the maximum in March. In general the surface isohalines, during any month, Figs. 30 - 41, trend North and South with salinity increasing offshore except in May when the lowest salinity appears to lie between Cape Ann and Provincetown. This is probably the result of the Merrimack spring runoff drifting southward across the middle of the Bay. Except for May, Cape Cod Bay tends to be fresher than the rest of Massachusetts Bay but only by a fraction of salinity.

The surface and bottom salinity cycle at Boston Lightship is diagrammed in Figure 42, in which the surface maximum, mean and minimum decadal values for the period 1956-1970 are given as well as the average monthly bottom values. The mean range varies from 30.7 to 32.4‰ with the maximum during January and February, the minimum in May, followed by a gradual virtually linear return to the January maximum. Extreme salintiy values range from about 28 to nearly 33‰.

The mean bottom salinity ranges from 31.6 to 32.5. For half the year, October to March, the average difference between the surface and bottom salinity is 0.2‰ or less. This substantiates the temperature data that the water column is well mixed during this period. The minimum salinity is observed at all depths in May as a direct result of the spring runoff.

Figure 43 combines the average temperature and salinity information at Boston Lightship for 1956-1970 into a T/S diagram. The diagram reiterates how the warming cycle which commences in March continues to August at the surface, to October at the bottom, when it commences to chill back to the February condition. The salinity cycle is at a maximum during the coldest period, freshens throughout the water column in response to the runoff cycle to a minimum in May, and gradually through mixing and advection returns to the winter maximum.

The current systems in Massachusetts Bay

The currents in coastal waters may be classed by their time scales, for instance--mean currents, tidal currents and higher frequency currents associated with turbulence and waves. The most obvious are the tidal currents, frequently modified by the wind, less obvious are the mean or residual currents and least recognizable and only recently observed in this area are the high frequency phenomena.

The basis for our understanding of the Massachusetts Bay current system lies in the body of data outlined in Table I, kindly prepared by Richard Boehmer of the Commonwealth of Massachusetts, Department of Natural Resources. The recent data (NOAA-NOS recent files) are still undergoing analysis. The data are available on tape. It is expected they will be published by NOS in a Special Publication within a couple of years.

The semi-diurnal tidal oscillation into Massachusetts Bay results in a mean tidal rise and fall of about 9 feet. Spring ranges are about 1.5' greater. The flood current sets westward into Massachusetts Bay, the ebb northeastward to eastward. The velocity at strength over Stellwagen Bank increases from about 0.2 knot at the northern end to over 1 knot at the southern end. The tidal current at Boston Lightship is weak, averaging less than 0.2 knot at strength. The velocity and direction of the current there is greatly influenced by the wind.

For some distance northwestward of Cape Cod the tidal currents have a slight set into Cape Cod Bay on the flood and out of the Bay on the ebb. Along the north shore of Massachusetts Bay the flood sets in a generally southwesterly direction and the ebb northeasterly. The speeds of the tidal currents are on the order of 0.5 knot or less and as remarked above are greatly influenced by the force and direction of the wind. The flood sets westward, the ebb eastward off the entrance to Boston Harbor, increasing to over 1 knot as the entrance is approached.

Figs. 44 and 45 diagram the generalized direction of the tidal wave at the time of maximum flood and ebb.

Tidal currents have been measured 1 meter above the bottom in various parts of Massachusetts Bay. Maximum current speeds (26 - 29 cm/sec) in the deep basin west of Stellwagen Bank were lower than those over the bank (32 - 47 cm/sec) or inshore off Marblehead (43 cm/sec). Thus near-bottom current speeds appear to be strongest in the outer part of the Bay including the channel between Cape Cod and Stellwagen Bank, weaker near shore and weakest in the deep basin.

The residual drifts are inferred from drift bottle and seabed drifter data. Massachusetts Bay lies on the western side of the cyclonic Gulf of Maine eddy. This Gulf of Maine eddy provides a southward flow across the mouth of Massachusetts Bay, achieving its fastest drifts during April and May. The surface drift is thus southward at speeds of 1 - 5 nautical miles per day (nmpd) east of Stellwagen Bank. West of Stellwagen Bank the drift tends to follow the coastline, i.e. southwestward south of Cape Ann into Massachusetts Bay, southward past Boston Harbor thence cyclonically around Cape Cod Bay and northeastward past Race Point. These drifts range between 1 and 5 nmpd.

Bottom residual drifts are an order of magnitude slower than the surface drifts, i.e. 0.2 to 0.5 nmpd. In general these drifts are southward to southeastward across Stellwagen Bank and in the deeper waters to the east of the bank, and southward to southwestward (i.e. with a shoreward component) over the inner part of Massachusetts Bay. The southerly drift in Massachusetts Bay extends into Cape Cod Bay.

Recent studies west of Stellwagen Bank indicate that the seasonal thermocline is subjected to a 6 - 8 minute oscillation for about 2.5 hours during the tidal flood. Maximum vertical displacement of the internal wave occurs at a depth of 20 m. Long-crested short-wavelength narrow surface bands, parallel with the sill, propagating westward, were measured concurrently with the high-frequency temperature oscillations. It appears that some 9% of the tidal energy appears to be converted into semi-diurnal internal waves in summer occasioned by the sweep of the incoming tide over Stellwagen Bank when the seasonal thermocline is just above the sill depth of the bank.

ANNOTATED BIBLIOGRAPHY

Hydrography

Anonymous 1949
Tidal current charts, Boston Harbor. Third edition. Nat'l Ocean Surv. Ser. #504: 1 p, 12 pl.

A set of 12 charts depicting by means of arrows and figures the direction and speed of the tidal current for each hour of the tidal cycle, referenced on time of beginning of flood or ebb at Deer Island Light or time of high or low water at Boston.

Anonymous 1951
Hydrographic survey in the Boston area, Hazel III--Cruise 1. W.H.O.I. Ref. 51-62: 4 p, 5 figs, m/s rept.

T°C, S°/₀₀, dissolved O_2, transparency in Cape Cod and Massachusetts Bays, Boston Harbor, May 1951.

Anonymous 1951
Hydrographic survey in the Boston area, Hazel III--Cruise 2. W.H.O.I. Ref. 51-93: 7 p, 9 figs, m/s report.

T°C, S°/₀₀, dissolved O_2, transparency, coliform bacteria in Cape Cod and Massachusetts Bays, Boston Harbor, June 1951.

Anonymous 1951
Hydrographic survey in the Boston area, Hazel III--Cruises 5 and 6. W.H.O.I. Ref. 51-94: 7 p, 8 figs.

T°C, S°/₀₀ in Cape Cod and Massachusetts Bays, Boston Harbor, August and September 1951.

Anonymous 1953
Density of sea water at tide stations, Atlantic coast, North and South America. Spec. Publ., U.S. Coast and Geod. Surv. #279: 62 p.

Record for Boston 1922-1952

	J	F	M	F	M	A	M	J	J	A	S	O	N	D	ann.
mean density	1.0216	216	[illegible]	216	199	198	206	213	222	223	223	225	222	219	215
S°/₀₀	29.3	[illegible]	[illegible]	29.3	27.1	26.9	28.0	28.9	30.1	30.2	30.2	30.4	30.1	29.7	29.1

ntains max., mean max., mean min. and min. densities.

Anonymous 1953
Report on currents, Boston Harbor. U.S. Coast and Geod. Surv. m/s report. (GC-309-B6A5)

Contains data from 1929, 1948 and 1952 surveys. 23 stations occupied at 3 depths for 4 days each.

Anonymous 1954
Boston Harbor tide survey 1952-1953. U.S. Coast and Geod. Surv. m/s report. (GC-309-B6U5 1952/53)

Nine volumes of data on tides from surveys in the Boston Harbor area. Charts and tables in photostat form.

Anonymous 1955
Surface water temperatures at tide stations, Atlantic coast, North and South America. Spec. Publ., U.S. Coast and Geod. Surv. #278: 69 p.

Record for Boston, Massachusetts 1922-1944

	J	F	M	A	M	J	J	A	S	O	N	D	ann.
max.	7.2	5.0	8.9	14.4	17.2	21.1	22.2	23.9	23.9	17.8	14.4	10.0	
mean	1.56	0.94	3.06	6.94	11.50	15.72	18.06	18.67	17.39	13.33	8.83	4.06	10.0
min.	-2.0	-2.0	-1.1	0.0	6.7	10.0	13.9	13.3	12.8	7.8	2.8	-1.1	

Anonymous 1972
Tidal Current Tables, 1973, Atlantic Coast of North America. U.S. Dept. Comm., N.O.A.A., National Ocean Survey.

Table 1 -- lists time of slack water, time of maximum current, and velocity of maximum flood and ebb current (for Boston Harbor, Deer Island Light, flood direction is 260°T, ebb direction 085°T).

Table 2 -- lists position; time differences for slack water and maximum current; velocity ratios for maximum flood and ebb, and maximum currents (direction and average velocity) for flood and ebb referenced on Boston (Table 1) for 6 locations next to the coast north of Boston Harbor, 6 locations in the Boston Harbor approaches, 35 locations in Boston Harbor and 12 locations in Cape Cod Bay.

Anraku, M. 1964
Influence of the Cape Cod Canal on the hydrography and on the copepods in Buzzards Bay and Cape Cod Bay, Massachusetts. I. Hydrography and distribution of copepods. Limnol. and Oceanogr. 9(1):46-60.

Seventeen temperature and salinity surveys and plankton collections were made from June 1959-May 1961. In summer there is a thermocline in both Buzzards Bay and Cape Cod Bay with complete mixing of the water in the canal itself. With a westerly tidal flow, the colder water of Cape Cod Bay enters the canal but scarcely penetrates as far as the northern end of Buzzards Bay. When the tide runs to the east, the warmer water from Buzzards Bay moves toward Cape Cod Bay but does not extend far out into it. In winter, horizontal and vertical temperature differences almost entirely disappear throughout the area. In general, a relatively high salinity is found in Cape Cod Bay and at the southern stations in Buzzards Bay, with less saline "canal" water separating them.

Beardsley, R. C. and B. Butman 1972
Hydrography and currents in Massachusetts Bay. Chapter 3 in Methods of observation and analysis of harbor and coastal pollution. Special Summer Program 19.81S. Lecture notes M.I.T. Depts. of Civil Engineering and Meteorology: 24 p.

Discusses the bathymetry, sediment distribution, hydrography and current patterns.

Bigelow, H. B. 1913
Oceanographic cruises of the U.S. Fisheries Schooner "Grampus" 1912-1913. Science 38:599-601.

General description of the commencement of oceanography in the coastal waters of northeast United States.

Bigelow, H. B. 1914
Explorations in the Gulf of Maine, July and August 1912, by the U.S. Fisheries Schooner "Grampus." Oceanography and notes on the plankton. Bull. Mus. Comp. Zool., Harv., 58 (2):29-147.

Description of T, S°/₀₀ and plankton data for subject period.

Bigelow, H. B. 1914
Oceanography and plankton of Massachusetts Bay and adjacent waters, November 1912 - May 1913. Bull. Mus. Comp. Zool. Harv., 58(10):383-419.

Description of results of cruises during subject period.

Bigelow, H. B. 1915
Exploration of the coast between Nova Scotia and Chesapeake Bay, July and August, 1913, by the U.S. Fisheries Schooner "Grampus." Oceanography and plankton. Bull. Mus. Comp. Zool., Harv., 59(4):149-359.

The real explanation of the low temperature of the coastal waters is to be found neither in upwelling, nor in a northern current, but in the land climate of eastern North America.

Bigelow, H. B. 1917
Explorations of the coast between Cape Cod and Halifax in 1914 and 1915, by the U.S. Fisheries Schooner "Grampus." Oceanography and plankton. Bull. Mus. Comp. Zool., Harv., 61(8):161-357.

Cruise narrative, detailed description of data and interpretation of same.

Bigelow, H. B. 1922
Explorations of the coastal waters off the northeastern United States in 1916 by the U.S. Fisheries Schooner "Grampus." Bull. Mus. Comp. Zool., Harv., 65(5):85-188.

One T/S profile across Massachusetts Bay. "Grampus" 10340, -41, -42 July and 10397, 10403 October.

Bigelow, H. B. 1925
Oceanic circulation. Science 62:317-319.

Description of general circulation in Gulf of Maine.

Bigelow, H. B. 1927
Physical oceanography of the Gulf of Maine. Bull. U.S. Bur. Fish. 40(2):511-1027.

Classic report on subject area in exhaustive detail.

Bigelow, H. B. 1927
Dynamic oceanography of the Gulf of Maine. Bull. Nat. Res. Couns., Wash. 61:206-211.

General description of cyclonic circulation based on T, S‰, plankton, drift bottles and Bjerknes hydrodynamic theory.

Bue, C. D. 1970
Stream flow from the United States into the Atlantic Ocean during 1931-60. Contributions to the hydrology of the United States. Geol. Surv. Water Suppl. Pap. 1899-I.

	mean ft^3/sec	Drainage area $miles^2$	$ft^3/sec/miles^2$
Reach 9: Mass. Bay, Cape Ann to the 42nd parallel. *Includes 466 cfs sewage waste for Boston	1,368*	674	2.03
Reach 10: 42nd parallel to Orleans, mainly Cape Cod Bay	420	240	1.75

Bumpus, D. F. and A. H. Clarke 1947
Transparency of the coastal and oceanic waters of the western Atlantic. W.H.O.I. Tech. Rept. 10. Hydrography of the Western Atlantic. 12 p. m/s rept.

A compilation of data from literature and original observations in both Secchi depths and extinction coefficients.

Bumpus, D. F. 1951
Memorandum on oceanographic information concerning Boston Harbor. W.H.O.I. Ref. 51-7: 9 pp. m/s rept.

Geology, tides, tidal currents, weather, sea water temperature, salinity and density, refraction of sound, marine borers and fouling organisms.

Bumpus, D. F., W. S. Butcher and W. D. Athearn 1951
Literature survey of oceanographic information concerning Boston Harbor. W.H.O.I. Ref. 51-84: 46 p, 20 figs. m/s rept.

Geology; bathymetry, formations, areal geology, structure, bedrock topography, seismicity, magnetic and

gravity anomalies, surficial geology, probings and borings, rate of sedimentation, dumping grounds, cable areas, wrecks.

Tidal information; tides, mean sea level, tidal currents, flushing.

Weather; climate, open season for navigation, prevailing winds, storms, sea and swell, fog, precipitation, air temperature, relative humidity.

Sea water; temperature, salinity, density, refraction of sound, transparency.

Biological influences; borers, fouling, noise makers, ambient noise.

Bumpus, D. F. 1952
Hydrographic survey in the Boston area. Results of Hazel III, Cruise 8. W.H.O.I. Ref. 52-19: 8 p, 6 figs. m/s rept.

T°C, S°/₀₀, Transparency of Cape Cod and Massachusetts Bays, Boston Harbor, Nov. 1951; flushing time of Boston Inner Harbor.

Bumpus, D. F. and C. G. Day 1952
Hydrographic survey in the Boston area. Results of Hazel III, Cruise 10. W.H.O.I. Ref. 52-43: 4 p, 5 figs. m/s rept.

T°C, S°/₀₀, Transparency of Boston Harbor and Massachusetts Bay, Feb.-March 1952; flushing time of Boston Inner Harbor.

Bumpus, D. F. and C. G. Day 1952
Hydrographic survey in the Boston area. Results of Hazel III, Cruise 12. W.H.O.I. Ref. 52-58: 6 p, 6 figs. m/s rept.

T°C, S°/₀₀, Transparency of Boston Harbor and Massachusetts Bay, April 1952; flushing time of Boston Inner Harbor.

Bumpus, D. F., W. S. Butcher, W. D. Athearn and C. G. Day 1953
Inshore survey project Boston. Final Harbor Report. W.H.O.I. Ref. 53-20: 39 p, m/s report.

Bathymetry, bottom sediments, bottom samples and cores. (Residence, bulk density, water content, organic content, color, rate of sedimentation, magnetic anomalies). Runoff data, T°C and S°/₀₀, climatology (air temperature, precipitation, wind, fog). Flushing time of Boston Inner Harbor, transparency, ice, fouling, noise producers, bioluminescence, kelp, sea and swell, sound velocity.

Bumpus, D. F. 1957
Surface water temperatures along the Atlantic and Gulf coasts of the United States. U.S.D.I., F.W.S., Spec. Sci. Rept.--Fish. #214: 153 pp.

Includes Cape Ann, Gloucester Harbor, Boston Harbor, Boston Lightship and Provincetown.

Bumpus, D. F. 1957
Oceanographic observations, 1956, east coast of the United States. U.S.D.I., F.W.S., Spec. Sci. Rept.--Fish. #233: 132 p.

Boston Lightship: Water temperature ranged from slightly less than 37°F, surface to bottom in March to 68°F at the surface in August and almost 52°F at the bottom in October. The thermocline was well developed from mid-June to mid-September. Surface S‰ ranged from 32.5 in January to 30.5 in mid-June with recovery to nearly 32.0 by the end of the year. Bottom salinities were ½ to ¾‰ higher than the surface salinities during the period of thermocline development, but generally tended to follow the surface salinity at each end of the year.

Bumpus, D. F. and C. G. Day 1957
Drift bottle records for Gulf of Maine and Georges Bank, 1931-1956. Spec. Sci. Rept.--Fish #242: 61 p.

Data.

Bumpus, D. F. 1960
Sources of water contributed to the Bay of Fundy by surface circulation. Jour. Fish. Res. Bd. Canada 17(2):181-197.

Runoff a critical factor in inducing the cyclonic movement about the Gulf of Maine.

Bumpus, D. F. 1961
Drift bottle records for the Gulf of Maine, Georges Bank and the Bay of Fundy, 1956-58. Spec. Sci. Rept.--Fish. #378: 127 p.

Charts and data.

Bumpus, D. F. and J. Chase 1964
Changes in the hydrography observed along the east coast of the United States. Int. Comm. N.W. Atlantic Fish., Spec. Publ. #6: 847-854.

Peak in winter air temperature in 1931 and 1952. In August little long-term change except for a maximum in 1951. There was a drop during the next decade in August, annual and February means.

Boston Lightship temperature record from 1925-1941, 1956 to 1963. Small sea water winter temperature maximum in 1932. Observations since 1956 show no significant temperature trends in any season.

Bumpus, D. F. and L. M. Lauzier 1965
Surface circulation on the continental shelf off eastern North America between Newfoundland and Florida. Am. Geogr. Soc., Serial Atlas of the Marine Environment, 7: 4 pp, 8 pl. Appendix.

Monthly and seasonal patterns of surface circulation inferred from drift bottle data.

Bumpus, D. F. 1973
A description of the circulation on the continental shelf of the east coast of the United States. Progress in Oceanography 6(4):111-157.

Monthly patterns of surface and bottom circulation inferred from drift bottle and sea-bed drifter data.

Butman, B. 5/11/71
Some short term current observations in Massachusetts Bay. Unpublished m/s report. 36 pp.

Currents are generally weak (0.1 - 0.3 kt) except over Stellwagen Bank, in the channel north of Provincetown and in Boston Harbor (0.3 - 0.7 kt). Speeds decrease with depth.

Continuity calculations using order of magnitude velocities, are consistent with westerly flooding of the tide into Massachusetts Bay and an easterly ebb.

The flushing time appears to be on the order of 9 days to 2 months.

Caldwell, J. M. 1955
Tidal currents at inlets in the United States. Proc. Amer. Soc. Civ. Eng. 81(716):1-12.

Tidal currents at inlets along the coasts of the U.S. are classified into 3 basic types on the basis of pertinent tide and current data. The hydraulic characteristics of the 3 types are discussed and sedimentary formulae, giving the basic variable controlling the inlet velocities are set forth.

Boston Harbor is in Class 2 -- Adequate entrance with the estuary ca. 1/4 tide wave length or shorter, the strength of flood precedes the high tide by 2-3.5 hrs, tidal range inside the inlet substantially equal to the tide range outside.

Precedence of current before tide -- 2^h 58'
Tide Range -- Outside 9.3', Inside 9.5', Ratio 1.02
Est. effective depth of estuary -- 30'
Est. tide length of estuary -- 8 miles
Est. 1/4 tide wave length -- 66 miles
Ratio -- Est. length/1/4 tide length -- 0.12
Mean velocity at strength of tide -- 2.87'/sec.

Chase, J. 1964
Oceanographic observations, 1961, east coast of the United States. U.S.F.W.S. Data Rept. 1: 176 p.

The surface temperature at Boston was below normal during most of the first 6 months but to a lesser extent than was the case at the two observation posts off the Maine coast.

Bottom temperatures were near normal except for a small lag in the summer warming. A weak thermocline was formed after a complete overturn associated with hurricane Ester.

Salinity was near normal with a minimum at the surface in late May.

Chase, J. 1965
Oceanographic observations, 1962, east coast of the United States. U.S.D.I., F.W.S., Data Rept. 9.

Boston Lightship: An apparently normal occurrence not remarked before was an indraft of cold saline water along the bottom from offshore sometime during May or June. It was not evident in 1958, 1959 and 1960 due to lack of data, but was present in 1961 and 1962 and, to a limited extent, in 1957.

Chase, J. 1966
Oceanographic observations, 1963, east coast of the United States. U.S.D.I., F.W.S., Data Rept. 10: 173 p.

The cold saline bottom water intrusion noted in late May and early June at Boston Lightship.

Chase J. 1967
Oceanographic observations, 1964, east coast of the United States. U.S.D.I., F.W.S., Data Report 18: 177 p.

Record low surface salinity in late April at Boston Lightship.

Chase, J. 1967
Recent trends of temperature along the New England coast. I.C.N.A.F. Redbook IV: 37-41.

The recent (since 1952) surface cooling is apparently less pronounced in the summer months. The short record of bottom temperatures shows cooling in all seasons.

Chase, J. 1969
Oceanographic observations, 1965, east coast of the United States. U.S.D.I., F.W.S., Data Report 32: 156 p.

A cold year is apparent in the temperatures of air and surface water at Boston. New record low temperatures were noted in 16 of the 33 decads in which surface temperature was reported. Bottom water temperatures were record lows in all decads reported except for late April through mid-June.

The surface salinity minimum came in early June, 2 decads later than normal. Salinities were above normal from mid-April through the end of the year, but did not exceed the records established in the drought year of 1957.

Chase, J. 1969
Oceanographic observations, 1966, east coast of the United states. U.S.C.G. Oceanogr. Rept. #29: 149 p.

Small range in surface salinity at Boston and Portland lightships. Minimum was in June, later than normal.

Chase, J. 1969
Surface salinity along the east coast of the United States. Deep-Sea Res. suppl. to 16:25-29.

The annual salinity cycle, with decadal maxima, means, and minima for 12 lightship locations are graphed and discussed.

Chase, J. 1971
Oceanographic observations along the east coast of the United States, January-December 1967. U.S.C.G. Oceanogr. Rept. #38: 149 p.

At Boston, surface salinities reflected the drought, with high values early in the year and by a late minimum. The indraft of cold, saline water at the bottom was delayed until August.

Chase, J. 1971
Oceanographic observations, 1968, along the east coast of the United States. U.S.C.G. Oceanogr. Rept. #45: 148 p.

The cold winter was reflected by subnormal water temperatures at all depths during the first three months. Surface water temperature returned to normal in April and remained near or above normal for the rest of the year.

The indraft of cold, saline bottom water, noted in some warm seasons, was not observed in 1968.

Salinity was near normal in the first half of the year, but salinity minimum was delayed until 1 July.

Chase, J. 1971
Oceanographic observations along the east coast of the United States, January-December 1969. U.S.C.G. Oceanogr. Rept. #46: 147 p.

A return of cold, saline bottom water occurred in late August.

Chase, J. 1972
Oceanographic observations along the east coast of the United States, January-December 1970. U.S.C.G. Oceanogr. Rept. #53: 145 p.

Marked fluctuations in sea surface temperatures at mid-year in response to air temperature fluctuations.

Colton, J. B., Jr. 1964
History of oceanography in the offshore waters of the Gulf of Maine. U.S.F.W.S. Spec. Sci. Rept.--Fish. #496: 18 p.

Detailed chronological account of the development of oceanography in the Gulf of Maine.

Colton, J. B., Jr. 1968
Recent trends in subsurface temperatures in the Gulf of Maine and contiguous waters. Jour. Fish. Res. Bd. Canada 25(11):2427-2437.

A comparison was made of 1955-60 and 1961-66 monthly mean 200-m temperatures in eight 1-degree quadrangles in the Gulf of Maine and along the continental slope between Nova Scotia and Long Island. Temperatures were appreciably lower in all areas during the latter period. The subsurface temperature trends parallel trends in surface temperature previously documented. The distribution of temperature at 200 m along the edge of the continental shelf during March, May-June, and September 1965-1966 and the distribution of temperature, salinity and dissolved oxygen on sections made across the continental shelf in September 1954, 1965 and 1966 showed that the cooling and warming trends are accompanied by changes in the composition of the subsurface water. Cold years occur when slope water borders upon the 200-m isobath and the ratio of coastal to Central Atlantic water is low.

Colton, J. B., Jr. 1968
A comparison of current and long-term temperatures of continental shelf waters, Nova Scotia to Long Island. I.C.N.A.F. Res. Bull. 5:110-129.

Temperatures at 0, 20, 50 and 100 m were appreciably colder in 1954-64 than the means for 1940-59. The causes of the trends are discussed.

Colton, J. B., Jr., R. R. Marak, S. R. Nickerson and R. R. Stoddard 1968
Physical, chemical and biological observations on the continental shelf, Nova Scotia to Long Island, 1964-1966. U.S.F.W.S., Data Report #23: 190 p.

Lists and graphs the seasonal distribution of temperature, salinity, dissolved oxygen and chlorophyll.

Colton, J. B., Jr. 1969
Temperature conditions in the Gulf of Maine and adjacent waters during 1968. Jour. Fish. Res. Bd. Canada 26(10): 2746-2751.

Surface-water temperatures at Boothbay Harbor, Maine were appreciably higher in 1968 than in 1967. This check in the recent coastal cooling trend was reflected in offshore surface and subsurface temperature conditions and was accompanied by a shift in the relative position of coastal and slope water along the edge of the continental shelf.

Colton, J. B., Jr. and R. R. Stoddard 1972
Average monthly sea water temperatures, Nova Scotia to Long Island, 1940-1959. Amer. Geogr. Soc. Serial Atlas of the Marine Environment 21: 2 p, app, 10 pl.

Monthly summary of major temperature features.

Colton, J. B., Jr. and R. R. Stoddard 1973
Bottom-water temperatures on the continental shelf, Nova Scotia to New Jersey. NOAA Technical Report NMFS Circ-376: 55 p.

Monthly average bottom-water temperatures and long-term annual minimum and maximum bottom-water temperatures over the subject area are presented in 14 figs.

Day, C. G. 1958
Surface circulation in the Gulf of Maine as deduced from drift bottles. U.S.F.W.S. Fishery Bull. 58:443-472.

Description of the seasonal cycle in the circulation pattern.

Day, C. G. 1959
Oceanographic observations, 1957, east coast of the United States. U.S.D.I., F.W.S. Spec. Sci. Rept.--Fish. #282: 123 p.

Includes annual temperature and salinity cycle at Boston Lightship.

Day, C. G. 1959
Oceanographic observations, 1958, east coast of the United States. U.S.D.I., F.W.S., Spec. Sci. Rept. 318: 119 p.

Includes annual temperature and salinity cycle at Boston Lightship.

Day, C. G. 1960
Oceanographic observations, 1959, east coast of the United States. U.S.D.I., F.W.S. Spec. Sci. Rept. Fish. 359:114 p.

Includes annual temperature and salinity cycle at Boston Lightship.

Day, C. G. 1963
Oceanographic observations, 1960, east coast of the United States. U.S.D.I., F.W.S. Spec. Sci. Rept. Fish. 406: 59 p.

Includes annual temperature and salinity cycle at Boston Lightship, and summary for previous 5 years.

Elliott, F. E., W. H. Myers and W. L. Tressler 1955
A comparison of the environmental characteristics of some shelf areas of eastern United States. J. Wash. Acad. Sci. 45(8):248-259, 4 figs.

Attempt to bring together certain overall aspects of the environmental features of the region, including physiography, temperature, salinity, currents, sea level, transparency, color, climatology, and fouling.

Fish, C. J. 1929
Production and distribution of cod eggs in Massachusetts Bay in 1924 and 1925. Bull. U.S. Bur. Fish. 43[1927]II: 253-296.

A very definite and constant counterclockwise drift carries cod eggs out of Massachusetts Bay. Bottles launched in Cape Cod Bay in February strand between Wellfleet and Race Point, rate of drift 1.5 m.p.d. Bottles launched in Massachusetts Bay drifted easterly out of the Bay at 4.4 m.p.d. In May the tendency is southerly toward the northern and eastern side of Cape Cod, at ca. 3 m.p.d. Those launched a few miles off the "North Shore" move W-SW to strand near by.

Fleming, R. H. and F. E. Elliott 1956
Some physical aspects of the inshore environment of the coastal waters of the United States and Mexico. Geogr. Jour. 122(4):456-465.

General comparison of drainage basins, runoff, sediment load, coastline classification, surface water T and S°/₀₀ and tide.

Glude, J. B. 1955
The effects of temperature and predators on the abundance of the soft-shell clam, *Mya arenaria*, in New England. Trans. Amer. Fish. Soc. (1954) 84:13-26.

An increase in the abundance of green crab in the northern parts of its present range is correlated with the current warm cycle.

Graham, J. J. 1970
Coastal currents of the western Gulf of Maine. I.C.N.A.F. Res. Bull. 7:19-31.

The most prominent feature of the circulation along the coast was upwelling. Water drifts parallel to or offshore from the coast at the surface with a compensatory movement inshore along the bottom.

Gran, H. H. and T. Braarud 1935
A quantitative study of the phytoplankton in the Bay of Fundy and the Gulf of Maine. Jour. Biol. Bd. Canada 1(5): 279-467.

Includes observations on hydrography, chemistry and turbidity.

Haight, F. J. 1942
Coastal currents along the Atlantic coast of the United States. U.S.D.C., C.&G.S., Spec. Publ. 230: 73 p.

Charts and tables of tidal, residual and wind currents for numerous locations, including 2 in Massachusetts Bay.

U.S.S. Easthampton	42°24.1'N, 70°23.8'W		
Mar-May 1919	G.T. Time	Dir. T.	Speed (kt)
min. before flood	11.13	122	0.02
Flood strength	01.92	248	0.16
min. before ebb	05.22	110	0.04
Ebb strength	08.63	063	0.18

Boston Lightship	42°20.4'N, 70°45.4'W		
Sep-Dec 1913	G.T. Time	Dir. T.	Speed (kt)
min. before flood	10.42	170	0.04
Flood strength	01.50	262	0.15
min. before ebb	04.12	305	0.01
Ebb strength	07.92	082	0.14
June 1926-June 1927			
min. before flood	09.97	120	0.01
Flood strength	00.55	267	0.08
min. before ebb	03.87	050	0.01
Ebb strength	07.17	088	0.08

Velocity (kts + Dir. T.)

Hours after Greenwich Transit	0	1	2	3	4	5	6	7	8	9	10	11	12
Easthampton	0.12	0.15	0.16	0.15	0.09	0.04	0.05	0.13	0.18	0.18	0.11	0.02	0.09
	228	244	250	258	250	127	077	065	058	070	065	110	207
Boston L/S	0.07	0.08	0.06	0.03	0.01	0.05	0.07	0.08	0.08	0.05	0.01	0.04	0.07
	260	269	263	287	054	080	087	090	082	078	120	255	253

Time of HW at Boston after Greenwich Transit 03.76 hrs
Time of LW at Boston after Greenwich Transit 09.93 hrs

Non-tidal current velocity (kts + Dir. T.) at Boston L/S

J	F	M	A	M	J	J	A	S	O	N	D
0.03	0.03	0.06	0.10	0.04	0.04	0.05	0.00	0.01	0.02	0.04	0.04
120	165	114	136	041	056	038	---	345	117	000	117

Halpern, D. 1969
Observations of short period internal waves in Massachusetts Bay. Thesis submitted to the Department of Meteorology, M.I.T., on January 10, 1969 in partial fulfillment of the requirements for the degree of Doctor of Philosophy: 102 p. m/s.

See both items immediately following.

Halpern, D. 1971
Observations of short-period internal waves in Massachusetts Bay. Jour. Mar. Res. 29:116-132.

Temperature measurements made 9 km west of Stellwagen Bank indicate that the seasonal thermocline heaves up and down in phase with periods of 6-8 minutes for about 2.5 hours during flood tide. A sudden rise in the general temperature level accompanies the onset of the short-period motion. The maximum vertical displacement occurs at 20 m below the surface. The distribution of the displacements agrees within 10%

with the eigenfunction of the first mode of internal gravity waves; the eigenfunction was computed from measurements of density and velocity. Long-crested short-wavelength narrow surface bands parallel to the sill were measured concurrently with the high-frequency temperature oscillations. The high-frequency fluctuations occurring at regular intervals seem to be internal waves of mode one propagating in the same direction with respect to the moving medium. Their generation is not clearly understood.

Halpern, D. 1971
Semidiurnal internal tides in Massachusetts Bay. Jour. Geophys. Res. 76(27):6573-6584.

Semidiurnal tidal internal gravity waves consisting of the first five modes account for over 50% of the fluctuations that occurred in temperature measurements made at fixed depths in Massachusetts Bay. The amplitude of the lowest mode is the largest, while that of the second mode is negligible. The minimum value of the Richardson number of the internal wave of five modes is unity, and there is an indication that during each tidal cycle a dynamic instability may occur. The total internal wave energy occurring in a bandwidth of 7.32×10^{-3} cph, centered on the semidiurnal frequency, is approx. 4.3×10^{5} ergs/cm^{2}, which is about 8.6% of the total energy of the barotropic tide. These results, which were deduced from linear theory, may not be entirely accurate because the asymmetry of the temperature trace suggests nonlinear wave profiles, and because of the possible presence of microstructure.

Halpern, D. 1972
Current meter observations in Massachusetts Bay. N.O.A.A. Technical Rept., ERL 229-POL 7. 36 p.

The circulation in Massachusetts Bay contains both external and internal tidal motions during the summer months. 7-minute period fluctuations with 50-second averaged speeds of about 50 cm/sec have been measured in Massachusetts Bay.

Kangas, R. E.
Lightvessel/lightstation oceanographic observations east coast of the United States January - December 1971. U.S.C.G. Oceanograph. Rept. #C.G. 373-59: 124 pp.

Localized upwelling was noted at Boston Lightship in mid and late July 1971 possibly associated with offshore winds.

Lee, C. 1972
Long nonlinear internal waves and quasi-steady lee waves. Ph.D. Thesis, Massachusetts Institute of Technology and Woods Hole Oceanographic Institution (also G.F.D. Report 72-2): 127 pp.

Previous observations of large amplitude internal gravity waves generated by tidal flow over a submarine ridge in Massachusetts Bay motivated the consideration of the general problem of internal gravity wave generation by time-dependent flow of a stratified, inviscid fluid over topography. An internal Korteweg and de Vries type equation for the stream function is derived using a three parameter expansion method, where the three small parameters correspond to nonlinear, dispersive, and non-Boussinesq effects. The nonlinear effect is found to be dependent crucially on the curvature of the basic density profile and vanishes for linear stratification, i.e., constant Brunt-Vaisala frequency. Numerical solutions to the KdV type equation for a variety of different conditions are then used to demonstrate the importance of nonlinearity on the generation of large amplitude internal waves in the breakdown of internal fronts. The numerical results are also in reasonable agreement with laboratory experiments in which a two-dimensional submarine ridge is moved to create transient internal disturbances. Additional numerical calculations show that a nonlinear model accurately describes the principal features observed in Massachusetts Bay.

Simple analytic models and laboratory experiments are also used to examine mixing and the generation of quasi-steady lee waves. A tall, rapidly oscillating ridge acts to mix the stratified fluid near the ridge; the circulation set up by the collapse of the mixed fluid is determined. In the second study, ray theory is used to analyze lee waves generated behind a low ridge being towed periodically through a stratified fluid.

Lee, C. and R. C. Beardsley 1974
The generation of long nonlinear internal waves in a weakly stratified shear flow. J. Geophys. Res. 79(3): 453-462.

Mathematical and laboratory model treatment of the internal wave problem. The model gives accurate estimates of the observed sharp warm front, the phase speed and the "wavelength" of the internal waves observed by Halpern over Stellwagen Bank.

Lindenkohl, A. 1883
Notes on the model of the Gulf of Maine constructed for the United States Fish Commission. Bull. U.S. Fish Comm. 3:449-454.

Interpretation (not necessarily accurate according to present day information) as to the source of island, capes and shoals and the effects of the tidal currents and wind systems upon them.

Manohar-Maharaj, V. 1973
Spring run-off into Massachusetts Bay, 1973. Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at Massachusetts Institute of Technology:97 p.

The depth mean salinity for the water of Massachusetts Bay from Cape Ann to Cohasset is computed at different times during the spring of 1973 to obtain the volume of fresh water in the Bay. This volume was then compared with the volume of fresh water entering via the rivers and the Deer Island Sewage treatment plant.

The Merrimac R. accounted for about 90% of the volume of fresh water.

Marak, R. R., J. B. Colton, Jr. and D. B. Foster 1962
Distribution of fish eggs and larvae, temperature, and salinity in the Georges Bank-Gulf of Maine area, 1955. U.S.D.I., F.W.S., Spec. Sci. Rept.--Fish. 411:66 p.

In addition to the fish egg and larvae data there are plots and tables of surface temperature and salinity.

Meade, R. H. 1971
The coastal environment of New England. New England River Basins Commission.

General discussion of the shape of the coastline, the coastal waters and sediments.

Mitchell, H. 1881
Physical hydrography of the Gulf of Maine. Rept. of the superintendent of the U.S.C.&G.S. showing progress of the work during the fiscal year ending with June 1879: 175-190.

Description of tidal heights and currents -- with some comments on the effect of Georges Shoal on tidal velocities.

Rathbun, R. 1887
Ocean temperatures of the eastern coast of the United States from observations made at 24 lighthouses and lightships. Fisheries and Fishery Industries of the United States. III App.:155-177, 32 ch.

Historical surface temperature data.

Redfield, A. C. 1939
The history of a population of _Limacina retroversa_ during its drift across the Gulf of Maine. _Biol. Bull._ _76_(1):26-47.

The observation on the distribution of _Limacina_ and the occurrence of S > $32°/_{oo}$ at 50 meters depth agree in indicating a drift during the winter period of the sub-surface waters through a distance of 150 miles in four months or at a rate of about 1.25 miles per day.

Redfield, A. C. and A. Beale 1940
Factors determining the distribution of populations of chaetognaths in the Gulf of Maine. _Biol. Bull._ _79_(3);459-487.

Sagitta elegans is the only chaetognath truly endemic to the region. The permanence of its occurrence appears to depend on the presence of a relatively stable eddy on Georges Bank. There is further discussion of the mechanism for the invasion of _S. serratodentata_.

Redfield, A. C. 1941
The effect of the circulation of water on the distribution of the calanoid community in the Gulf of Maine. _Biol. Bull._ _80_(1):86-110.

Observations made during a number of years have demonstrated that the center of the Maine eddy shifts its precise location from summer to summer. Observation of the velocity of the non-tidal drift at the surface made in shoal water about the margin of the Gulf indicate an average of seven miles/day, at which rate some three months would be required to complete the circuit of the eddy.

Schlee, J. and B. Butman 1974
Adjustment of inner shelf sediments to bottom currents off eastern Massachusetts. Relations Sedimentaires entre Estuaires et Plateaux Continentaux, Symposium vol., G. P. Allen, Ed. Institut de Geologie du Bassin d'Aquitaine. In press.

Currents measured one meter above the sea floor at six locations with various bottom sediments, show that the bottom is in approximate equilibrium with the maximum observed current speed, except where relict gravel exists. The average speeds are not strong enough to move the existing bottom material.

Schroeder, E. 1966
Average surface temperatures of the western North Atlantic. Bull. Mar. Sci. 16:302-323.

Average monthly surface temperatures plus 4 charts of seasonal averages. The basic circulation pattern and temperature regime are discussed on the basis of surface temperature distribution.

Schureman, P. 1928
Tides and currents in Boston Harbor. Spec. Pub. U.S.C. &G.S. 142:16 p.

Complete summary of all tide observations and tidal current observations for Boston Harbor, including Boston Lightship.

Stearns, F. 1964
Monthly sea-surface temperature anomaly graphs for Atlantic coast stations. U.S.F.W.S., Spec. Sci. Rept. Fish. 491: 3 p, 10 pl.

See Stearns, 1965.

Stearns, F. 1965
Sea-surface temperature anomaly study of records from Atlantic coast stations. J. Geophys. Res. 70(2):283-296.

Anomalies are based on record 1950-1959. A secular warming trend peaking the the early 1950's is demonstrated. This trend was strongest in the north and diminished progressively toward the south. Comparisons between the East and West coasts and the English Channel and European coast show partial negative correlation exists between anomalies of the E and W sides of the ocean. The negative correlation is greatest between northern stations and less so toward the S, where a positive correlation may exist at times.

Taylor, C. B. 1957
Extreme sea water temperatures and densities along the North Atlantic States during summer 1955. Jour. Mar. Res. 16(1):1-7.

During the summer of 1955, record high sea water temperatures were observed in harbors and coastal waters of the North Atlantic states. Record air temperatures also occurred during this period. It is concluded that high sea water temperatures were due in large part to continued high air temperatures. The record low densities (or salinities) during the same summer corresponded with the periods of hurricanes Connie and Diane, hence the high runoff following these storms was doubtless responsible. The lag between rainfall and noticeable dilution and the delay in return to normalcy depend on several factors including the amount of rain, type of estuary, and size of drainage basin.

Taylor, C. B., H. B. Bigelow and H. W. Graham 1957
Climatic trends and the distribution of marine animals in New England. Fish. Bull. 115, F.W.S. 57:293-345.

A long term upward trend in air T in N.E. is evident in the record. The increase has been greatest for the winter months.

Upward trends in winter sea temperature are shown for St. Andrews, Boothbay Harbor and Woods Hole.

Hydrographic data for the Gulf of Maine in 1953 and 1954 indicate an increase from 1-5°F throughout the water columns since the 1912-1926 period.

Northward shifts in abundance and distribution of some important commercial species are indicated by landing statistics and other data.

Numerous southern species of fishes and other marine forms have extended their recorded range northward since 1930. At least 2 have established resident populations north of their earlier recorded ranges.

Welch, W. R. 1967
Trends in monthly sea water temperatures, 1950-1966, at Boothbay Harbor, Maine. I.C.N.A.F. Redbook Pt. IV:33-36.

The warming trend in progress during the early 1950's reached its peak in 1953. Since then the temperature has shown a general decline. While summer and winter temperatures have followed the same downward trend as the annual means, the greater decrease has taken place during the winters.

Wilcox, B. W. 1958
Tidal movement in the Cape Cod Canal, Massachusetts. Proc. Amer. Soc. Civil Eng., Jour. Hyd. Div. 1586:1-9.

Variations in the form of the tidal wave at selected points, analysis of observations to obtain harmonic constants, and a practical method for predicting the tidal currents in the Canal are discussed. Diagrams are included to show the shape of the tide curves and also the agreement between predictions and observations of the tidal current at the railroad bridge.

Chemistry

Blanchard, R. L. 1965
U^{234}/U^{238} ratios in coastal marine waters and calcium carbonates. Jour. Geophys. Res. 70(16):4055-4061.

Water and live molluscan shell samples were collected simultaneously at seven locations on the sea coast of the U.S. Samples of silt, water and shells for an estuary, Merrimack, were also included. The water samples were analyzed for U^{238}, U^{234}, Ca and S °/₀₀; the shell samples for U^{238}, U^{234}, Ca and crystal structure. All water samples, regardless of S°/₀₀ or total U content, were found to have uranium activities ratios, $A_{U^{234}}/A_{U^{238}}$, within the experimental uncertainty of the 1.15 accepted for an oceanic environment. The results indicate that the normally higher uranium activity ratio of rivers does not increase the ratio of coastal waters above the 1.15 oceanic value. The activity ratios of all except two shell samples were similar to those of the surrounding sea water and to the oceanic 1.15 value. The AR of U leached from silt was fairly constant along the channel of the estuary (ca. 0.94 ± .02).

The AR of the water varied from 1.99 , 1.6 km above the estuary to 1.15 at the mouth.

The AR of shell were less than those found in an oceanic environment and were between the AR of the associated silt and that of the estuary water. The AR of the shell does appear to be governed by both the AR of the ocean water and that of the associated sediment.

Blanchard, R. L. and D. Oakes 1965
Relationships between uranium and radium in coastal marine shells and their environment. Jour. Geophys. Res. 70(12): 2911-2921.

Samples of sea water and bivalve molluscan shells were collected from 14 locations in the coastal waters of the U.S. (incl. Race Pt., Cape Cod) and one location near the Galapagos Is. The sea waters were analyzed for chlorinity, Ca, Ra^{226} and U. The shells were analyzed for Ca, Ra^{226}, U and crystal structure. The concentrations of U and Ra in inorganically deposited marine calcium carbonates were found to be most strongly dependent on the mineralogy of the carbonate, the species, and the concentration and ionic form of the nuclide in the water. The Ra/Ca ratio in the shells varied directly with the Ra/Ca ratio in the water. The correlation was especially evident when shells

composed only of aragonite were considered. In the case of U, this correlation was less evident. Any effects due to chlorinity or mean water temperature on the ratios of U/Ca or Ra/Ca in the shells was obscured by the strong mineralogical effect.

Blumer, M., M. M. Mullin and D. W. Thames 1963
Pristane in zooplankton. Science 140(3570):974.

The hydrocarbon pristane (2,6,10,14-tetramethylpentadecane) occurs in unusually high concentrations (1-3% of the body fat) in the three copepods *Calanus finmarchicus*, *C. glacialis* and *C. hyperboreus*. These planktonic crustaceans appear to be the primary source of the pristane in the liver oils of sharks and whales.

Clarke, G. L., G. C. Ewing and C. J. Lorenzen 1970
Spectra of backscattered light from the sea obtained from aircraft as a measure of chlorophyl concentration. Science 167(3921):1119-1121.

Spectra of sun and skylight backscattered from the sea were obtained from a low-flying aircraft and were compared with measurements of chlorophyll concentrations made from shipboard at the same localities and at nearly the same times. Increasing amounts of chlorophyll were found to be associated with a relative decrease in the blue portion of the spectra and an increase in the green. Anomalies in the spectra show that factors other than chlorophyll also affect the water color in some instances; these facts include other biochromes, suspended sediment, surface reflection, polarization and air light.

Colton, J. B., Jr. 1972
Short-term variations in estimates of chlorophyll abundance. I.C.N.A.F. Res. Bull. 9:81-84.

Short-term variation in total chlorophyll and in the depth of maximum chlorophyll abundance were observed at a drogue station in an area (Great South Channel) characterized by a well defined vertical temperature gradient and strong tidal currents. These variations were associated with vertical oscillations of the thermocline caused by internal waves.

Ketchum, B. H. 1951
The dispersion and fate of pollution discharged into tidal waters and the viability of enteric bacteria in the sea. W.H.O.I. Ref. No. 51-11:16 p, 3 tab, 4 fig. m/s report.

Sea water is bactericidal to coliform bacteria. This bacterial activity may be the most important factor in the natural clearing of polluted tidal waters. Dilution and predation by zooplankton are also effective in decreasing the bacterial population. Includes exchange ratios and coefficients of accumulation for Boston Inner Harbor, Dorchester Bay and President Roads.

Ketchum, B. H. and W. L. Ford 1952
Rate of dispersion in the wake of a barge at sea. Trans. Amer. Geophys. Union 33(5):680-684.

An analysis is presented of the dispersion of a pollutant discharged at sea from a barge. The pollutant in this cases contained 10% $FeSO_4$, the iron of which proved to be a convenient indication of dispersion in the sea since it may be observed to concentrations as low as 10 ppb. The distribution of iron in the wake is related to the rate of discharge and the horizontal mixing coefficient. This relationship provides a means of estimating the rate of discharge of the pollutant to meet specific concentration limits.

Ketchum, B. H. and N. Corwin 1965
The cycle of phosphorus in a plankton bloom in the Gulf of Maine. Limnol. and Oceanogr. Suppl. to 10:148-161.

There was a considerable decrease in inorganic and an increase of both particulate and dissolved organic P in the surface waters between 8-18 Apr. Much of the particulate P formed had sunk below the 50 m euphotic zone to deeper waters. Below 136 m there was no net change in any of the fractions of P and the change in ΣP for the entire water column was essentially 0. The average rate of primary production for the 10-day period was slightly more than 2 g C $m^{-2}day^{-1}$. Both the chlorophyll and particulate P data give indications of the sinking of particulate matter during the bloom. The sinking particles contain an unusually high proportion of chlorophyll compared to P.

Prince, J. S. 1971
An ecological study of the marine red algae Chrondrus crispus in the waters off Phymouth, Massachusetts. A thesis presented to the faculty of the Graduate School of Cornell University for the Degree of Doctor of Philosphy: 191 p.

Contains tabulations and charts of the temperature at E end of Cape Cod Canal and concentrations of PO_4, ΣP, NO_2, NO_3, NH_4, Si and S°/₀₀ off Manomet for the 1969-1970 period.

Rakestraw, N. W. 1932
Phosphorus and nitrogen in the neritic waters of the Gulf of Maine. Int. Rev. des ges Hydrobiol. u Hyd. 27(1):151-160.

Phosphates, nitrates and nitrites are exceedingly variable in neritic waters (off Frenchman's Bay, Maine). Factors other than the seasonal fluctuations of plankton govern these variations.

Rakestraw, N. W. 1933
Studies on the biology and chemistry of the Gulf of Maine. I. Chemistry of the waters of the Gulf of Maine in August 1932. Biol. Bull. 64(2):149-158.

Gives distributions of T, S°/₀₀, Nitrate-N, Nitrite-N, PO_4, O_2.

Rakestraw, N. W. and F. B. Lutz 1933
Arsenic in sea water. Biol. Bull. 65(3):397-401.

No regular significant increase in As concentration with depth.

The greater portion of As in sea water is present in the form of Arsenite.

Rakestraw, N. W. and H. E. Mahncke 1935
Boron content of sea water of the North Atlantic coast. Ind. and Eng. Chem. 7:425-426.

Boron conc. 4.75 mg/kg in Gulf of Maine stations. The ratio of boron to chloride is 0.000255 compared to 0.000240 for southern stations, indicating a slightly higher percentage of boron in the dissolved solids of the water in this region.

Rakestraw, N.W. 1936
The occurrence and significance of nitrate in the sea. Biol. Bull. 71(1):133-167.

An explanation of the production and utilization of nitrate and its place in the nitrogen cycle of the sea and the general process of marine metabolism (including data from Massachusetts Bay).

Redfield, A. C., H. P. Smith and B. H. Ketchum 1937
The cycle of organic phosphorus in the Gulf of Maine. Biol. Bull. 73(3):421-443.

The distribution of P present as inorganic phosphate, as dissolved organic compounds, and as particulate matter (detritus and micro-organisms) has been determined at all depths throughout the year at a station in the offing of Massachusetts Bay (50 mi NE of Highland Light).

In late winter over 90% of the P is in inorganic form and 3/4 of the remainder is present as soluble inorganic compounds.

In spring, Feb.-May, inorganic P is converted to organic form by photosynthesis in the upper layer of water. Most of this fraction sinks to considerable depths before undergoing decomposition. During summer, May-Nov., large quantities of dissolved organic P appears at all depths, indicating a very considerable transport of inorganic phosphate from deep water to the surface and sinking of an equivalent amount of P in particulate form to the depths in which organic compounds are liberated by decomposition. Decomposition appears to take place throughout the water column. During the winter, Nov.-Feb., the organic P compounds are converted to inorganic phosphate. This and vertical mixing of preformed phosphate are about equally important in bringing about equalization of phosphate concentration throughout the depth of water.

Redfield, A. C. and A. B. Keys 1938
The distribution of ammonia in the waters of the Gulf of Maine. Biol. Bull. 74(1):83-92.

NH_4 occurred in minimal concentrations at the surface and at all depths below 60 m in the deeper basins of the Gulf of Maine in May; maximum concentrations varying up to 45 mg N m^{-3} occurred in a definite stratum between 30 and 60 m.

In Sept. the concentration of NH_3 was uniform at all depths and increased as the distance from the open ocean increased, concentrations exceeding 50 mg N m^{-3} occurring in the western basin. In the tide ways of the N and S channels NH_3 is distributed uniformly with depth in both May and Sept.

In shallow waters its occurrence showed no regularity The occurrence of NH_3 may be correlated in part with the distribution of organic P compounds, of nitrite, and of zooplankton, so as to support the view that its distribution marks the place and intensity of organic decomposition.

Redfield, A. C. 1948
The exchange of oxygen across the sea surface. Jour. Mar. Res. 7(3):347-361.

About 30 x 10^4 cc of O_2 m^{-2} leaves the surface of the Gulf of Maine between the end of October and the latter part of March, a like amount re-entering from the atmosphere during the alternate period.

The net production and consumption of O_2 by organisms is sufficient to account for $^2/_5$ths of this exchange, the remainder being attributable to the effect of temperature on the solubility of oxygen.

The production of oxygen in April and May by photosynthesis is sufficient to account for the entire surface exchange. During the summer the exchange is attributable chiefly to decreasing solubility resulting from the warming of the water. In late fall and winter, excess oxygen consumption and increasing solubility are both responsible for the exchange. The pressure head of oxygen across the sea surface has been determined and found to agree in direction with the estimated movement of oxygen.

The exchange coefficient of O_2 is estimated to be ca. 13 x 10^6 cc/m^2/atmos/month in winter; 2.8 x 10^6 in summer. The seasonal difference in values obtained is attributed to conditions at the sea surface, such as sea state and stability, which cause errors in the measurements and estimations.

Spencer, D. W. and P. G. Brewer 1969
The distribution of copper, zinc and nickel in sea water of the Gulf of Maine and Sargasso Sea. Geo. Chim. Cosmo. Aeta 33(3):325-339.

Significant seasonal variations of concentrations of these elements in the surface can be attributed to biological removal. Either the rate of uptake of the metals by organisms is low or the rate of regeneration of the metals in the surface is high. In spite of the lack of observable seasonal variation, these elements appear to be non-conservative properties of sea water. In Sept. and Oct. the water of the upper 50 m, close to shore, has higher concentrations of the metals than the deeper inshore and the offshore waters. In March the surface and deep inshore waters show no difference and are similar to the offshore waters in Sept. and Oct. The summer increase is partially due to runoff and lack of mixing due to the stable water column.

Spencer, D. W. and P. L. Sachs 1970
Some aspects of the distribution, chemistry and mineralogy of suspended matter in the Gulf of Maine. Maine Geology 9:117-136.

Suspended matter in the Gulf of Maine decreases from the surface to about 50 m and then increases exponontially as the bottom is approached. Mineralogical and chemical data show that, from 50 m down, the suspended matter is dominantly layer silicates which are interpreted as resuspended bottom material. The chemical data show that in the upper 50 m particulate phosphorous, copper and zinc occur principally in organisms. There is, however, little evidence that significant amounts of these elements are reaching the bottom in an organic particulate form, and most appears to be regenerated in the water column. The distributions of particulate Al and Fe are controlled largely by suspended silicates, and there is no evidence that a free ferric hydroxide phase is important.

Vaccaro, R. F. 1963
Available nitrogen and phosphorous and the biochemical cycle in the Atlantic off New England. Jour. Mar. Res. 21:284-301.

The importance of NH_3 as a source of available N for phytoplankton populations off New England has been evaluated for August and January 1962. During Aug., when only trace amounts of nitrate persist in the photic zone, NH_3 appears to be the major source of available N. Therefore meaningful estimates of the relative amounts of N and P being assimilated at such times require consideration of the N occurring as NH_3. It is speculated that during late summer, when nitrate and nitrite concentrations are minimal, NH_3 forestalls the extreme degree of N deficiency known for lab cultures of N-starved algal cells.

Waksman, S. A., H. W. Reuszen, C. L. Carey, M. Hotchkiss and C. E. Renn 1933
Studies on the biology and chemistry of the Gulf of Maine. III Bacteriological investigation of the sea water and marine bottoms. Biol. Bull. 64(2):183-205.

Bacterial population of the sea can be divided into 3 groups on the basis of their habitat: (1) those forms which live in the sea bottom, especially in the surface layers; (2) those which live in free water, possible only when the water contains in solution organic and inorganic nutrient substances; (3) those which live largely associated with the planktonic organisms.

Sea water is a rather poor medium for the growth of bacteria, while the marine bottom is comparatively richer in the total number. Mud bottoms contain more living bacterial cells than sand bottoms. But waters above sandy bottoms contain more bacteria than water above muddy bottoms. This is possibly due to greater abundance of plankton, especially diatoms, in the shallower seas with sandy bottom, to greater mixing or greater adsorption of bacterial cells by the mud bottoms.

Anaerobic bacteria are found abundantly in marine mud. Their presence points to the continued decomposition of the plant and animal debris of the ocean on and in the sea bottom, even with an insufficient supply of O_2.

Walsh, G. E. 1965
Studies on dissolved carbohydrates in Cape Cod waters. I. General survey. Limnol. and Oceanogr. 10:570-576.

Distribution of dissolved carbohydrate (DCHO) in 21 bodies of water on or around Cape Cod (including 1 from Cape Cod Bay and 3 from estuaries off Cape Cod Bay) has been analyzed with reference to type of body of water, primary productivity, depth, and pH, Eh and organic content of the substrate. Water from 10 stations was analyzed in the autumn of 1963 and late winter of 1964. In the autumn the highest concentrations of DCHO (1.16-3.17 mg/ℓ) were found in highly productive estuaries. Other waters had DCHO concentrations ranging from 0.40-1.00 mg/ℓ. In deeper waters, concentrations were higher at the surface than at the bottom, suggesting the distribution is related to phytoplankton productivity. No relationship was found between DCHO conc. and pH, Eh or organic content of the substrate. At nine stations, concentrations during a late winter phytoplankton bloom decreased by 11-100% from those of the autumn. These data suggest that phytoplankton play a major role in regulation of DCHO concentration in natural waters.

Sea Level

Barghoorn, E. S. 1953
Recent changes in sea level along the New England coast, new archaeological evidence. Science 117:597-598.

Boylston Street fish weir provides evidence of submergence of 20' since human occupation in eastern Massachusetts. C^{14}- age determinations range from greater than 3851 ± 390 to less than 5717 ± 550 years. Assume weir to be 4500 years old, average rate of submergence of the land is ca. 6"/century from the construction of the weir to European occupation in 1600's.

Disney, L. P. 1956
Tide heights along the coast of the United States. Proc. Amer. Soc. Civil Eng. 81(666):1-9.

Elevations of extreme tides and secular variations in sea level are important factors in the design of coastal installations. Tables are given which list the highest and lowest tides as recorded at a number of stations. The yearly and secular variations in sea level for certain of the stations where the observations extend over a period of 20-60 years are presented.

Boston 1922-1952.
mean range 9.5'
average yearly highest above mean HW 3.1'
extreme high " " " 4.3' (21 Apr 1940)
average yearly lowest below " LW 2.8'
extreme low " " " 3.5' (25 Jan 1928, 24 Mar 1940)
mean rate of rise of sea level 0.014'/yr

Hicks, S. D. and W. Shofnos 1965
Yearly sea level variations for the United States. Proc. Amer. Soc. Civil Eng., Jour. Hyd. Div. 91:23-32.

A classification is based on the uniqueness of the grouping of sea level series by geographical areas in a plot of trend against standard error of estimate. The trend is a measure of the combined glacial-eustatic or tectonic effects or both. Average trends for the 1940-1962 common series are: north Atlantic sea level + 0.011'/hr.

Hicks, S. D. 1968
Long period variations in secular sea level trends. Shore and Beach Apr. 1968:32-36.

Boston -- trend for 1940-1962, 0.006'/yr.; 1940-1966, 0.003'/yr. The smoothed curves of the representative New England stations, Portland and Boston, suggest a crest in the long-period oscillation occurring about 1956, followed by a marked decrease in sea level.

Hicks, S. D. 1972
On the classification and trends of long period sea level series. Shore and Beach, April 1972: 20-23.

Although there was evidence of a reduction in the apparent secular trend during the period 1946 to 1964 in the northeast coastal area, data through 1970 indicate a return to the rates characteristic of the period 1928 to 1946. Boston 1940-1970, 0.0035'/yr.

Hicks, S. D. 1972
Vertical crustal movements from sea level measurements along the east coast of the United States. Jour. Geophys. Res. 77(30):5930-5934.

The rate of coastal subsidence relative to southern Maine is found to increase linearly a total of 0.214 cm/yr from southern Maine to Hampton Roads, Virginia. The absolute rate of subsidence closely approximates the relative rate, since sea level at Portland, Maine, is rising at a rate close to the estimated value for the rate of glacial-eustatic rise.

Hicks, S. D. 1973
Trends and variability of yearly mean sea level 1893-1971. N.O.A.A. Tech. Memo. Nos 12:13 p.

Sea level trends, their standard errors and variability are presented in tabular and graphical form for 43 locations along the coasts of the U.S.

Boston:

Since	Trend	Standard Error	Variability
1922	0.0093'/yr.	0.0008	0.0833
1940	0.0039	0.0014	0.0731

Johnson, D. W. 1910
The supposed recent subsidence of the Massachusetts and New Jersey coasts. Science 32(829):721-723.

Concludes that the evidence of recent subsidence along Massachusetts and New Jersey coasts must be considered inconclusive. That there has been subsidence in the past seems reasonably certain, but the author knows of no satisfactory evidence of recent subsidence in these areas.

Kaye, C. A. 1964
The upper limit of barnacles as an index of sea level change on the New England coast during the past 100 years. Jour. Geol. 72:580-600.

The sea level at Boston in the mid-nineteenth century was at approximately the same level as in the mid-20^{th} century, but it was approximately 0.5' lower at the turn of the century.

Kaye C. A. and E. S. Barghoorn 1964
Late quarternary sea-level change and crustal rise at Boston, Massachusetts, with note on the autocompaction of peat. Geol. Soc. Amer. Bull. 75:63-80.

16 radiocarbon dates from the Boston area are used to construct a sea-level curve going back 14,000 years B.P. Relative sea level was at +60' or higher 14,000 years B.P., dropping sharply to ca. -70' about 10,000 yrs. B.P. Sea level rose steadily to -2' ca. 3000 yrs. B.P. Since then sea level appears to have kept close to its present level, probably fluctuating ca. 1' during the standstill. A crustal movement curve, based on the relative sea level curve for Boston and the eustatic curve, indicates that ca. 290' of crustal rise occurred between 14,000-6000 yrs. B.P. with a maximum rate of uplift of ca. 0.2'/yr. at 12,750 yrs. B.P. and from 6000-3000 yrs. B.P. crustal subsidence occurred at Boston.

Milliman, J. D. and K. O. Emery 1968
Sea levels during the past 35,000 years. Science 162 (3858):1121-1123.

A sea-level curve of the past 35,000 years for the Atlantic continental shelf of the U.S. is based on more than 80 radiocarbon dates, 15 of which are

older than 15,000 years. Sea level 30-35,000 years ago was near the present one. Subsequent glacial growth lowered sea level to about -130 m 16,000 years ago.

Holocene transgression probably began about 14,000 years ago and continued rapidly to ca. 7000 years ago. Data from most shelves of the world agree with this curve, suggesting that it is approximately the eustatic curve for the period.

Marmer, H. A. 1944
The vertical stability of the coast at Boston in light of recent tide observation. Jour. Mar. Res. 5(3):206-213.

For a given year the heights of any one of the tidal datums (high water, sea level or low water) may be higher or lower than the preceding years, but it is evident that in general there has been a more or less progressive increase in height, ca. 0.0159'/yr (1922-1943).

Marmer, H. A. 1948
Is the Atlantic coast sinking? The evidence from the tide. Geogr. Rev., N.Y. 38(4):652-657.

The Atlantic coast of the U.S. has been subsiding since 1930 at the rate of 0.02'/yr and during the 35 years before 1930 the coastal region of the Middle Atlantic states has been subsiding at about $1/7^{th}$ of that rate.

Marmer, H. A. 1949
Sea level changes along the coasts of the United States in recent years. Trans. Amer. Geophys. Un. 30:201-204.

For the 1000-mile stretch of coast from Boston to Mayport, the conclusion is inescapable that there has been a relative subsidence of the coast during the past 17 years at a rate of about 0.02'/yr. We cannot determine from these data alone whether it is an absolute subsidence of the coast, an absolute rise in sea level or a combination of the two.

Meade, R. H. and K. O. Emery 1971
Sea level as affected by river runoff, Eastern United States. Science 173(3995):425-428.

Variations in annual river inflow account for 7 to 21% (7% in Gulf of Maine) of the total variation in annual average sea level along the Atlantic and Gulf of Mexico coasts of the U.S. This compares with 29 to 68% of the total variation that can be attributed to the secular rise in sea level, and with 10 to 50% of the variation that cannot be attributed to either river inflow or the secular rise.

Miller, A. R. 1958
The effects of winds on water levels on the New England coast. Limnol. and Oceanogr. 3(1):1-14.

Departures from mean sea level due to wind may be resolved into two components: (1) a component which refers to symmetrical sinusoidal variation of sea level departures as a function of wind direction and applies to the outer coast and the general level of Nantucket Sound in particular; (2) an asymmetrical component which refers to the responses of sea level at each observing station to local wind force and direction, fetch, length and local topography.

Redfield, A. C. 1967
Postglacial change in sea level in the western North Atlantic Ocean. Science 157(3789):687-692.

Radioactive carbon determinations of the age of peat indicate that at Bermuda, southern Florida, North Carolina and Louisiana the relative sea level has risen at ca. the same rate, 2.5×10^{-3} ft/yr (0.76×10^{-3} m yr^{-1}), during the past 4000 yrs. It is proposed tentatively that this is the rate of eustatic change in sea level. The rise in sea level along the NE coast of the U.S. has been at a rate much greater than this, indicating a local subsidence of the land. Between Cape Cod and northern Virginia coastal subsidence of 13' appears to have occurred between 4000 and 2000 yrs. ago and has continued at a rate of 1×10^{-3} ft/yr. since then. On the NE coast of Massachusetts subsidence of 6' occurred between 4 and 3000 years ago; since then sea level rose at an average of about 11×10^{-3} ft/yr. The part played by local subsidence or temporary departures from the average is uncertain.

Bibliographies

Anonymous 1952
Annotated oceanographic bibloography of selected ports of the eastern coast of the United States and their approaches. H.O. Pub. 760, Washington, D.C.:50 p.

Contains general, oceanographic, biological and geological bibliography for selected inshore areas of the east coast of U.S. and Panama Harbors.

Anonymous 1955
Provisional bibliography prepared in connection with draft agenda for conference on "Conservation of natural resources: the continental shelf and marine waters." U.S.N. Hydrographic Office, H.O. Misc. 16441:47 p.

Under the general headings Marine Biology, Marine Geology and Hydrography, Physical and Chemical Characteristics of Sea Water, Marine Meteorology this bibliography lists reference under sub-headings General, United States, Central America and South America.

Anonymous 1963
Bibliography of oceanographic publications: U.S. Govt., Interagency Committee on Oceanography Pamphlet 9:23 p.

500 titles by subject.

Anonymous 1969
Oceanography, a D.D.C. Bibliography, Vol. I. U.S. Govt., Defense Documentation Center, Alexandria, Virginia,:491 p.

1963-1968, abstracts and summaries of 1000 items.

Dees, L. T. 1964
List of Fish and Wildlife Service Papers on Physical and Chemical Oceanography, 1940-1962. Fishery Leaflet 561, (Washington, D.C.):14 p.

Papers by scientists at F.W.S. and contractors.

Depe, E. P. and L. H. Dawson 1961
Transmission of light in water: an annotated bibliography. NRL Bibliography No. 20 (Washington, D.C.):80 p.

600 references to American and foreign papers. Annotated, author--source, subject and geoprahical.

Fisher, L. J. 1960
An annotated bibliography of flushing and dispersion in tidal waters. U.S.N. Hyd. Off. SP-33 (Wash., D.C.):34 p.

Comprehensive through 1960, annotated or abstracted.

Heiner, W. R. 1967
A partial bibliography inshore survey program along Atlantic and Gulf coasts. Naval Oceanographic Office Informal Rept. IR No. 67-66:14 p.

Contains references to m/s reports generated under the Naval Oceanographic Office Inshore Survey Program during the early 1950's in the approaches to certain harbors of the Atlantic and Gulf Coasts.

Livingstone, R., Jr. 1965
A preliminary bibliography with KWIC index on the ecology of estuaries and coastal waters of the eastern United States. U.S.F.W.S. Spec. Sci. Rept.--Fish. 509:352 p.

A bibliography, containing more than 5470 references, as an initial effort to bring together references on the ecology of estuaries and coastal waters of the eastern U.S., stressing the period 1900-1960.

Rigby, M., Ed. 1965
Collected bibliographies on physical oceanography (1953-1964). Nat. Oceanogr. Data Center, Spec. Bibliographies No. 1 (Washington, D.C.), Amer. Meteor. Soc.:807 p.

Consolidates 13 special bibliographies which originally appeared in Meteorol. Abstr. Annotated.

Sears, M. 1971
Oceanographic Index, Author Cumulation 1946-1970, 3 vol. G. K. Hall and Co., Boston.

Covers all oceanography by author.

Sears, M. 1971
Oceanographic Index, Regional Cumulation 1946-1970, 1 vol.:706 p. G. K. Hall and Co., Boston

Covers all oceanography by region.

Sears, M. 1972
Oceanographic Index, Subject Cumulation 1946-1971, 4 vol. G. K. Hall and Co., Boston.

Covers all oceanography by subject.

Thompson, E. E. 1963
Oceanography, a report bibliography. Alexandria, Virginia, Defense Documentation Center:355 p.

1953-1963. Abstracts, 1500 references.

List of Figures

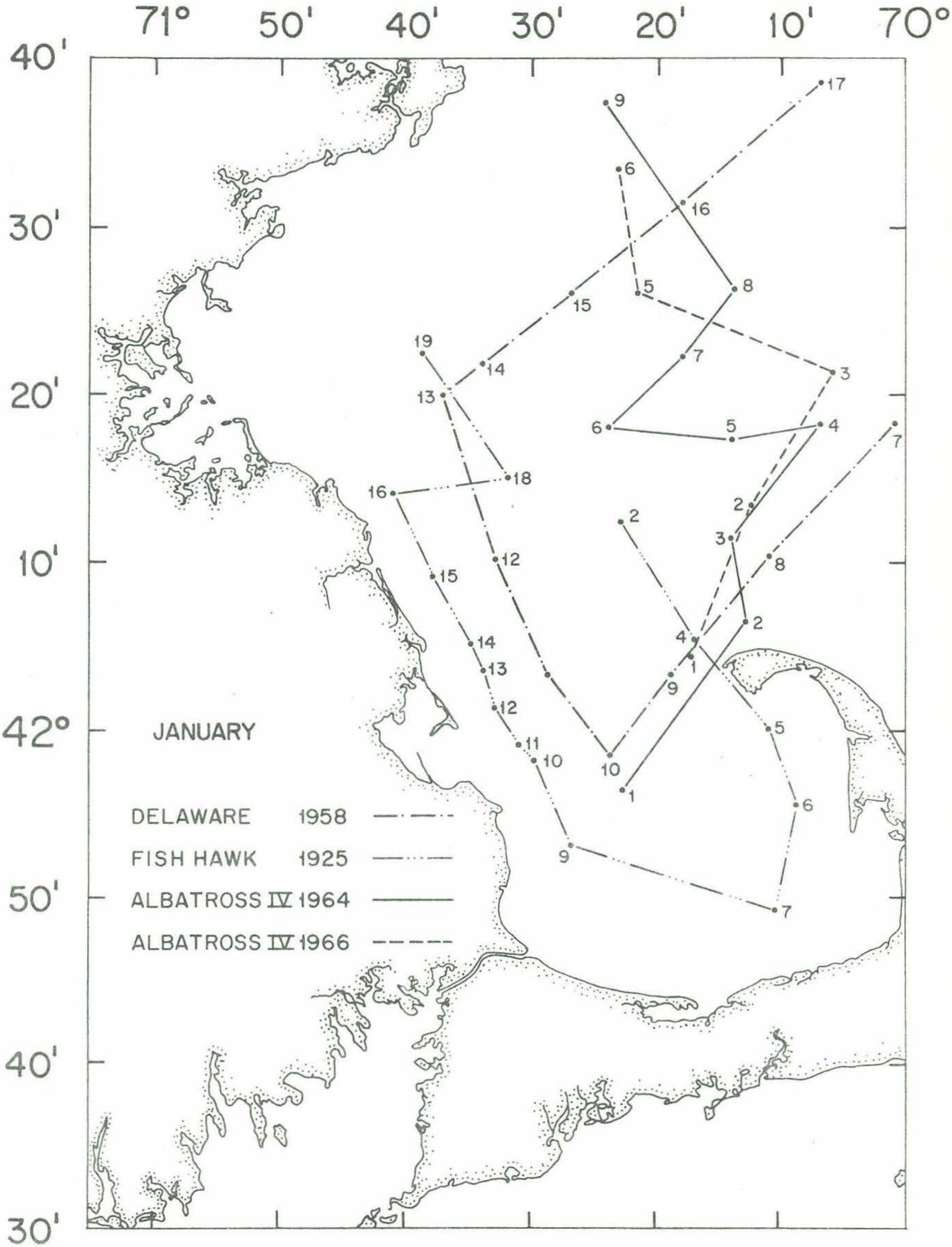

Figure 1: Location of temperature profiles for January

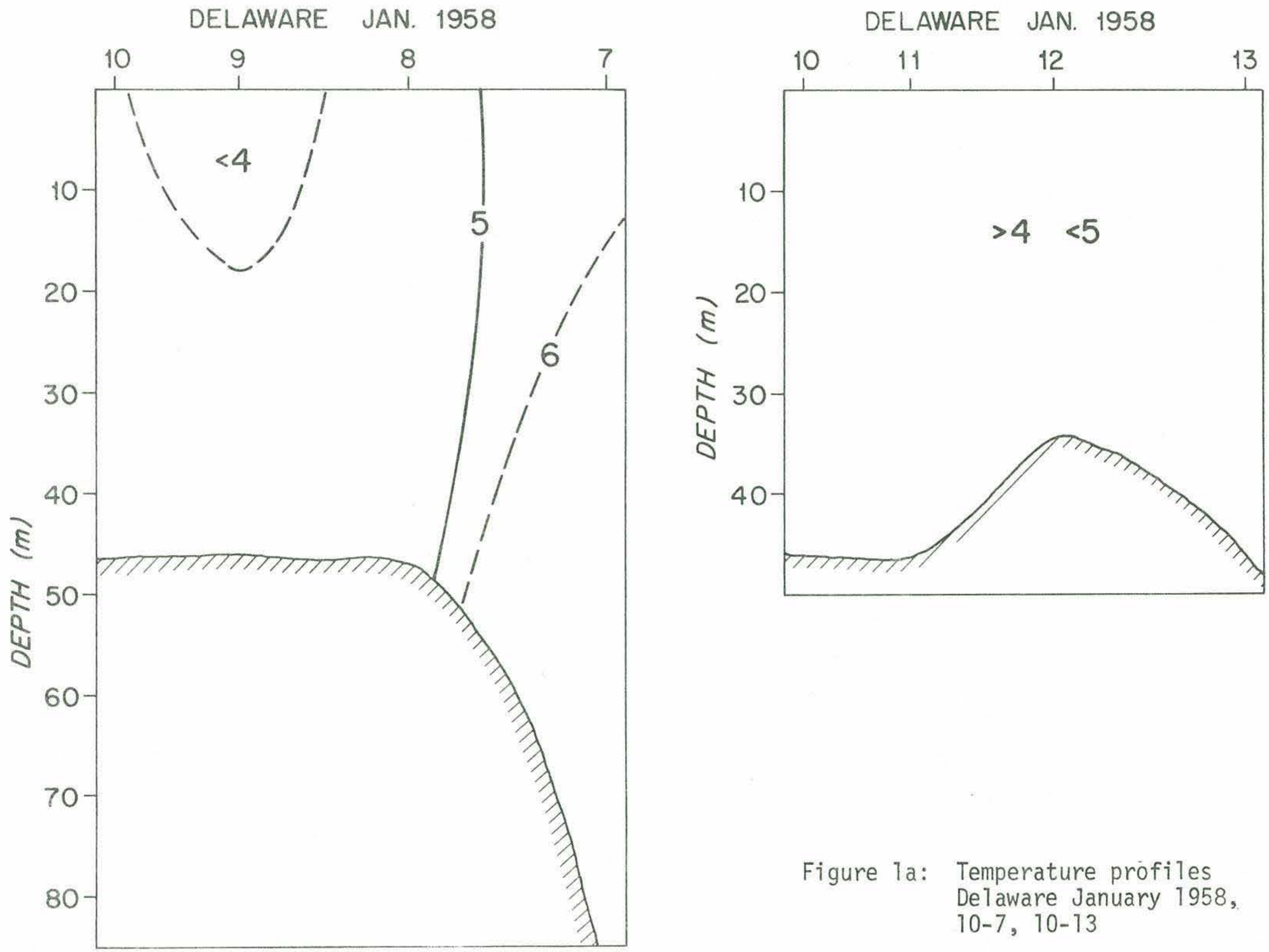

Figure 1a: Temperature profiles
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10-7, 10-13

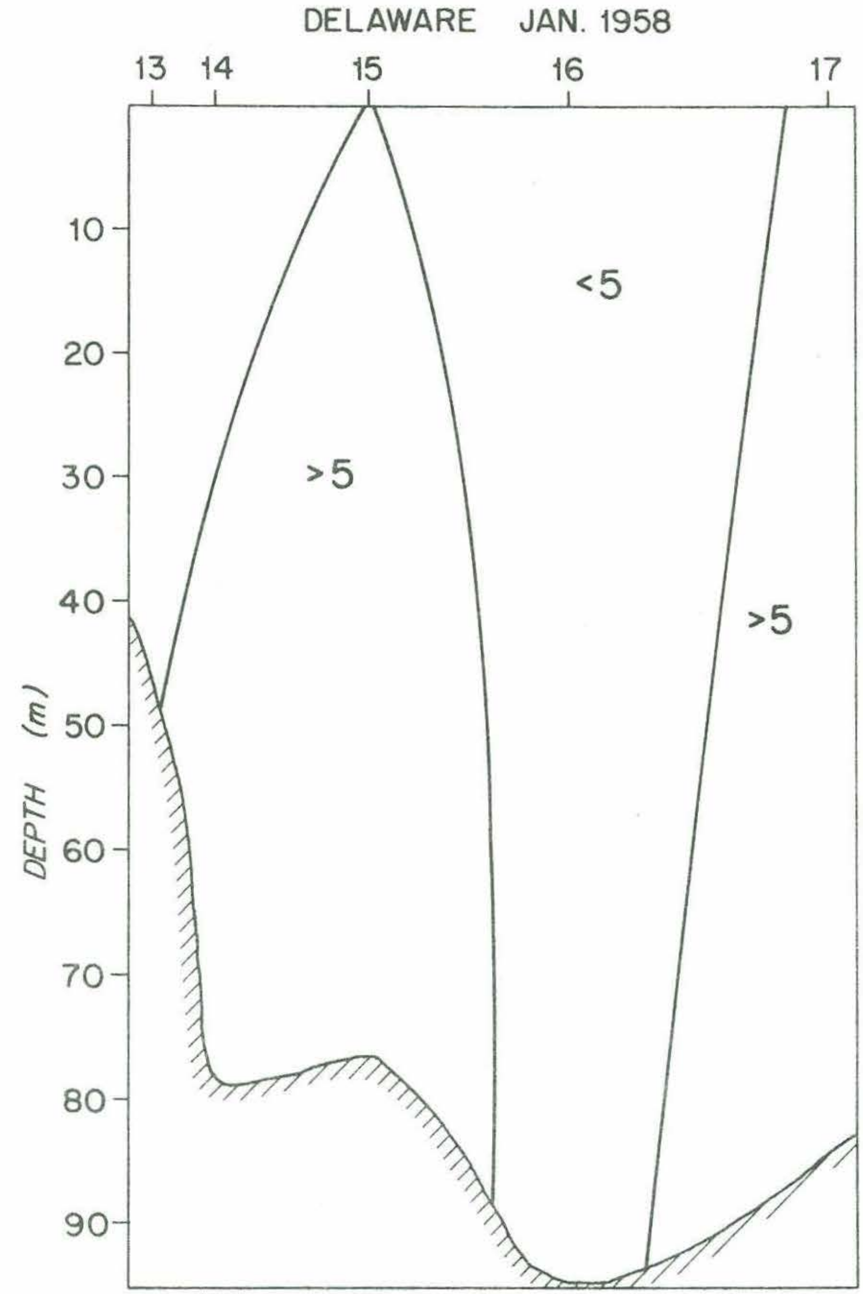


Figure 1b: Temperature profile Delaware January 1958, 13-17

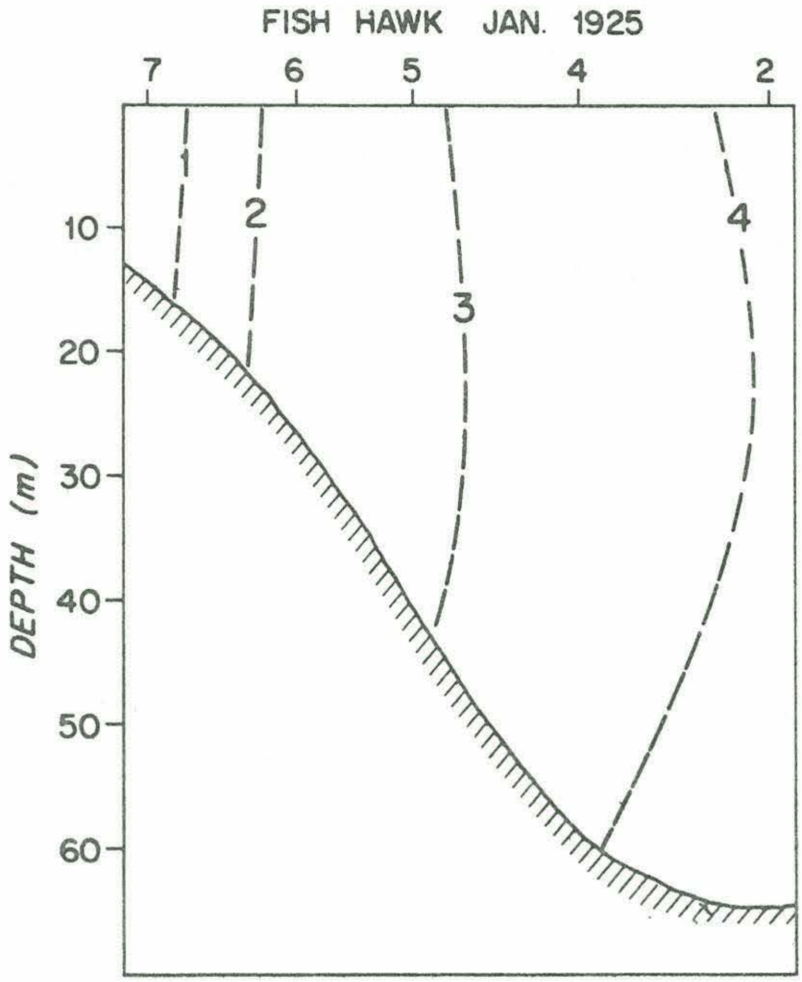


Figure 1c: Temperature profile Fish Hawk
January 1925, 7-2

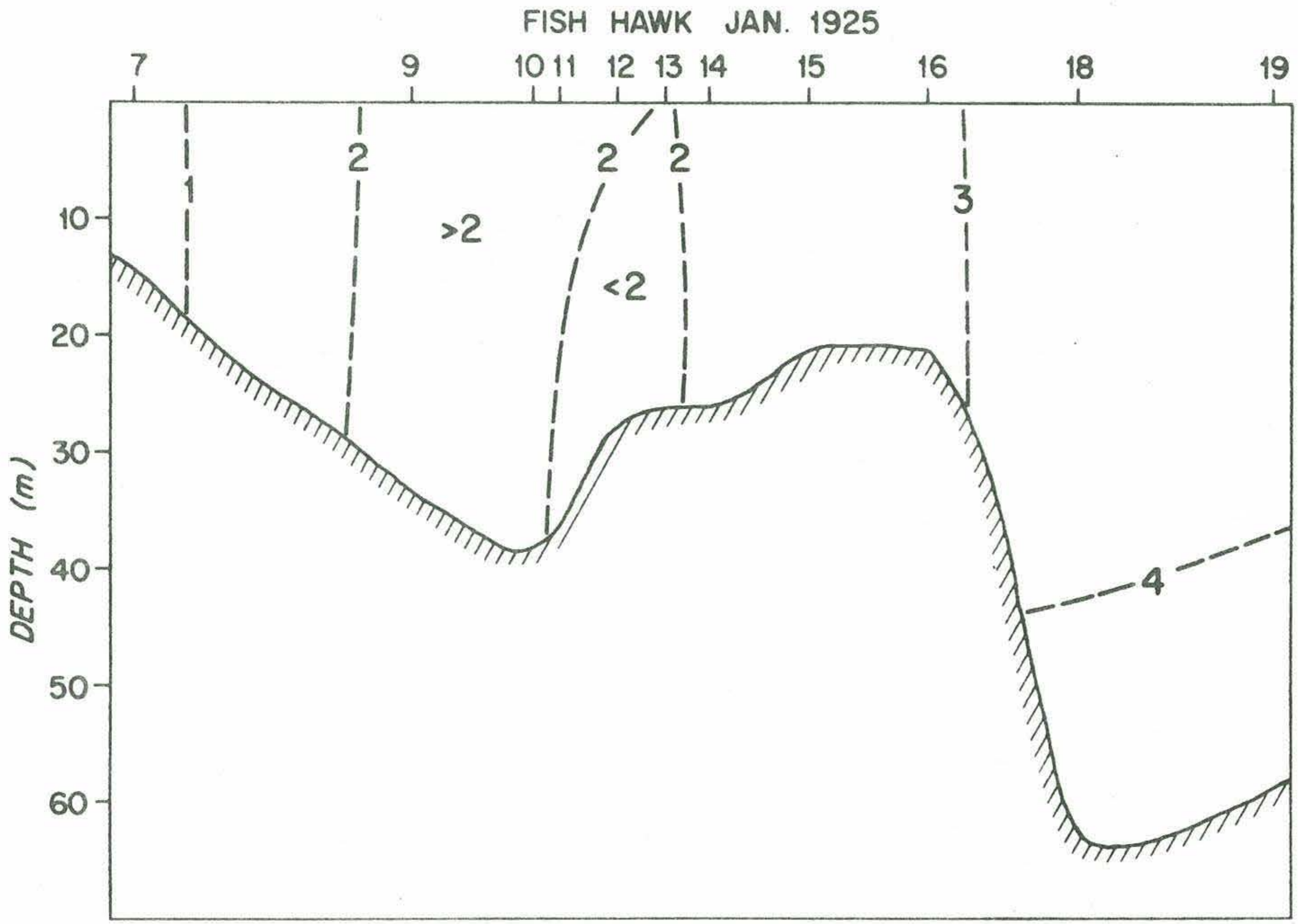


Figure 1d: Temperature profile Fish Hawk January 1925, 7-19

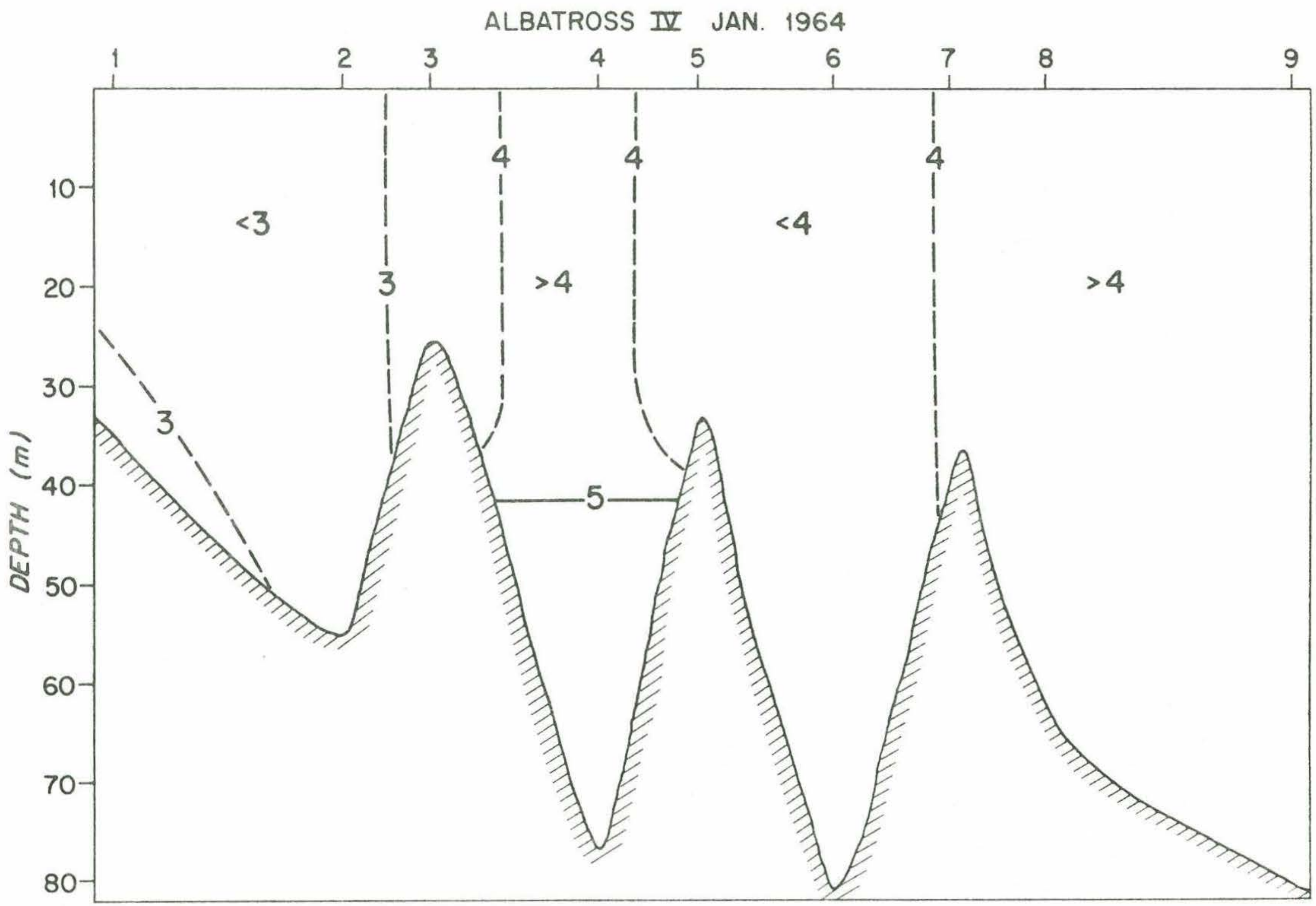


Figure 1e: Temperature profile Albatross IV January 1964, 1-9

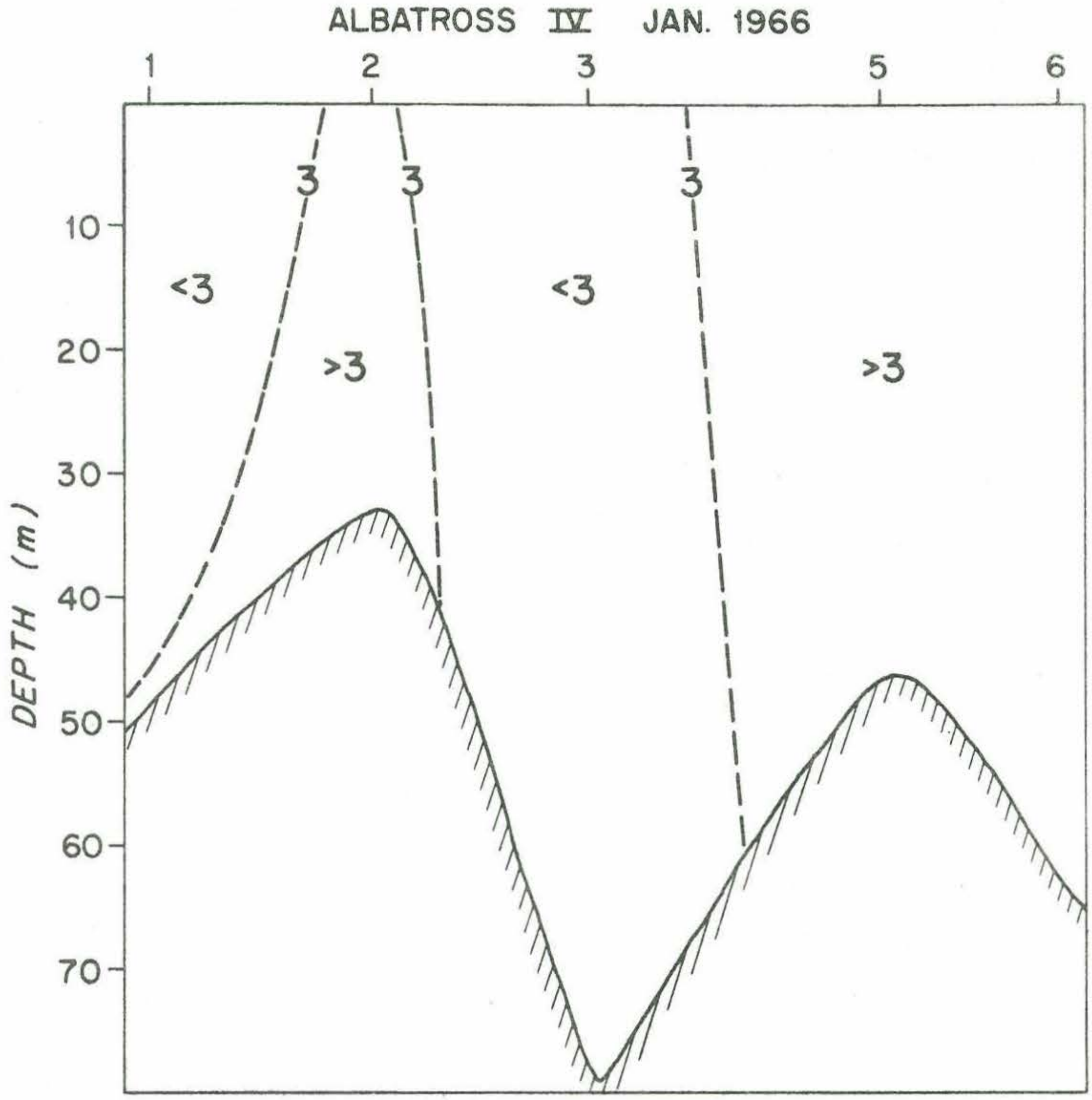


Figure 1f: Temperature profile Albatross IV January 1966, 1-6

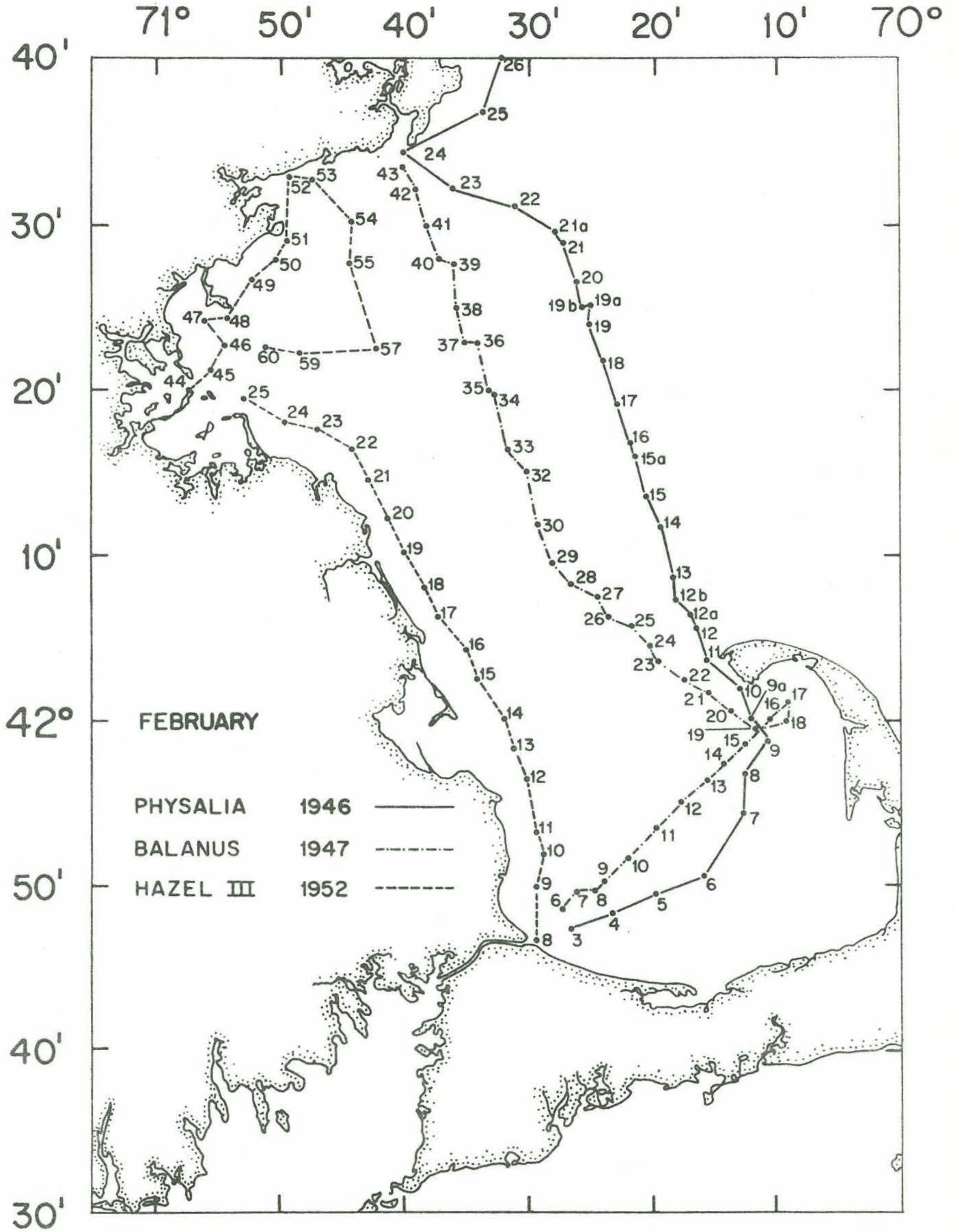


Figure 2: Location of temperature profiles for February

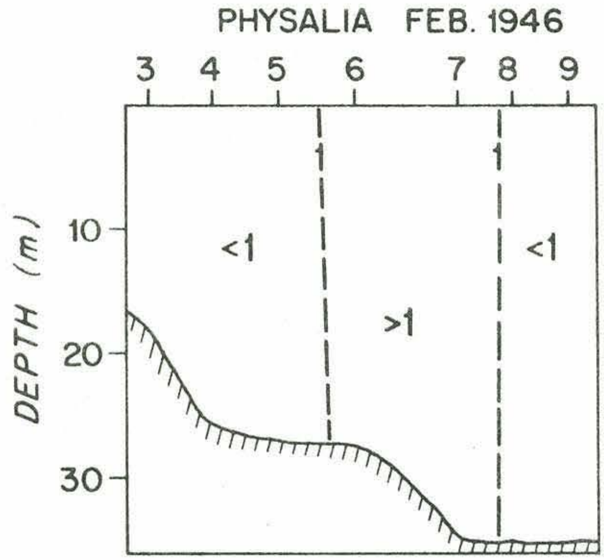


Figure 2a: Temperature profile Physalia
February 1946, 3-6

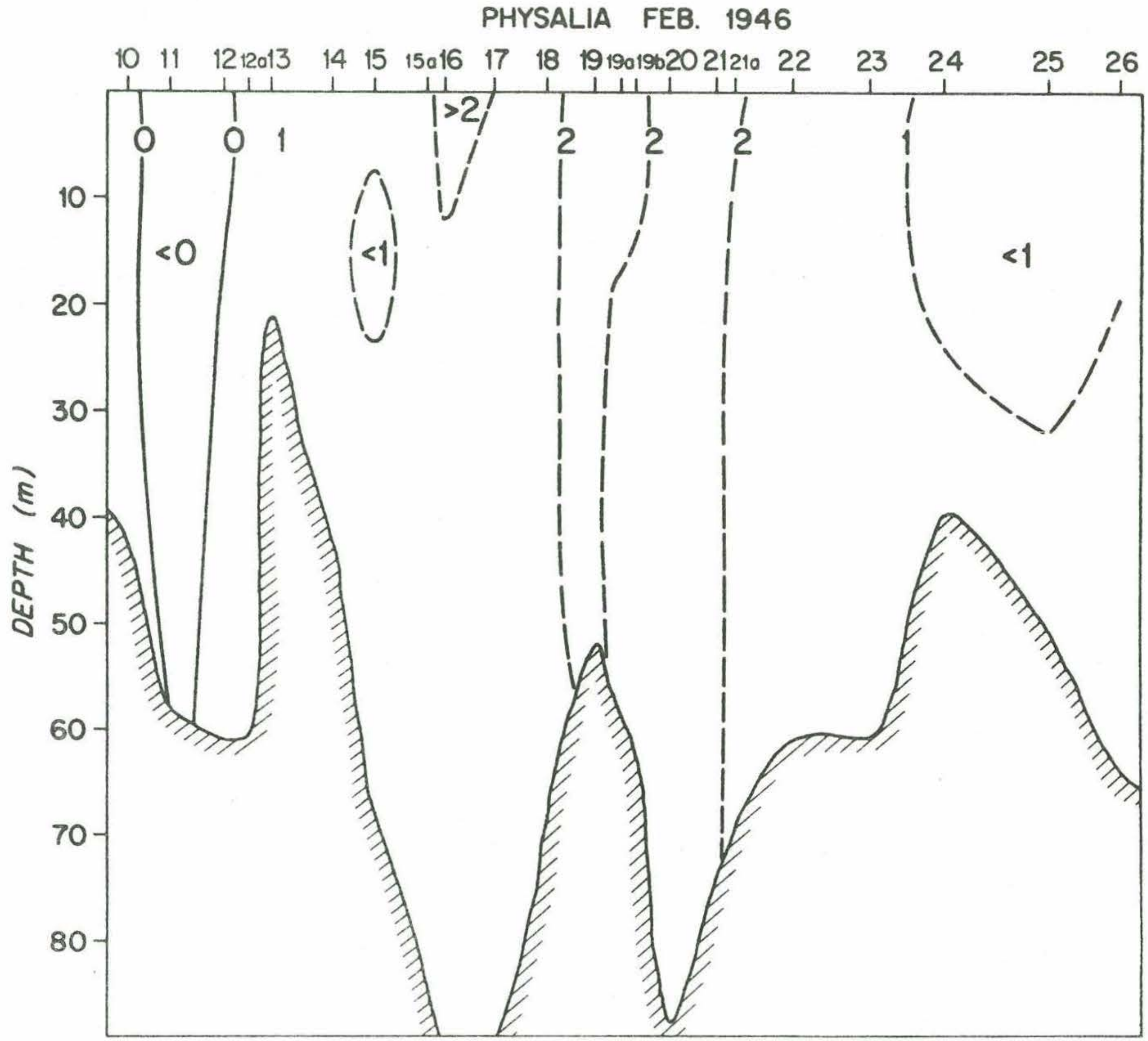


Figure 2b: Temperature profile Physalia February 1946, 10-26

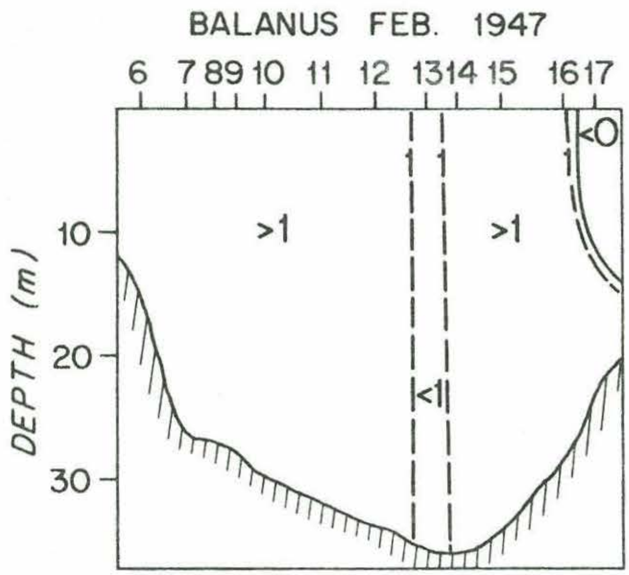


Figure 2c: Temperature profile Balanus
February 1947, 6-17

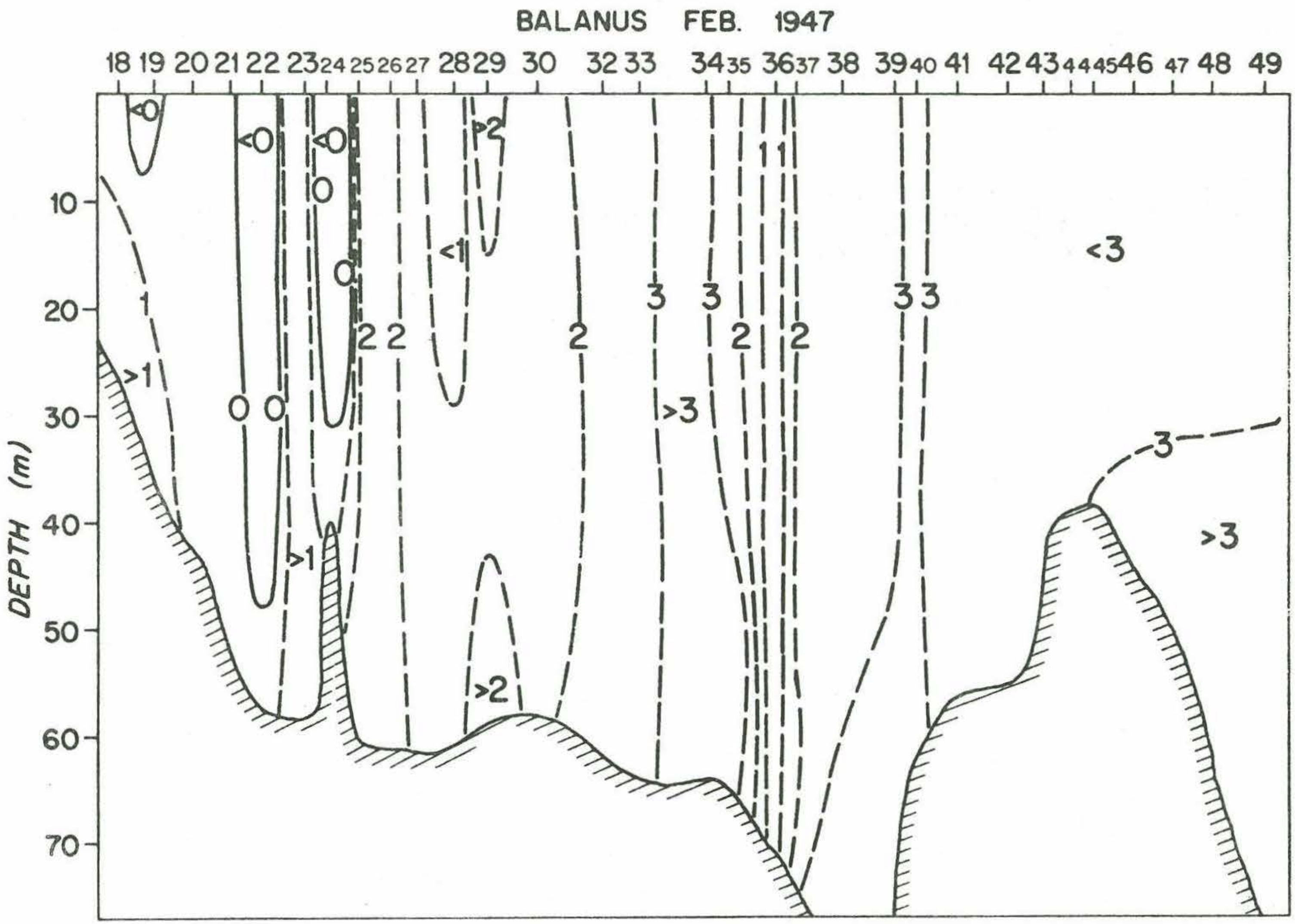


Figure 2d: Temperature profile Balanus February 1947, 18-49

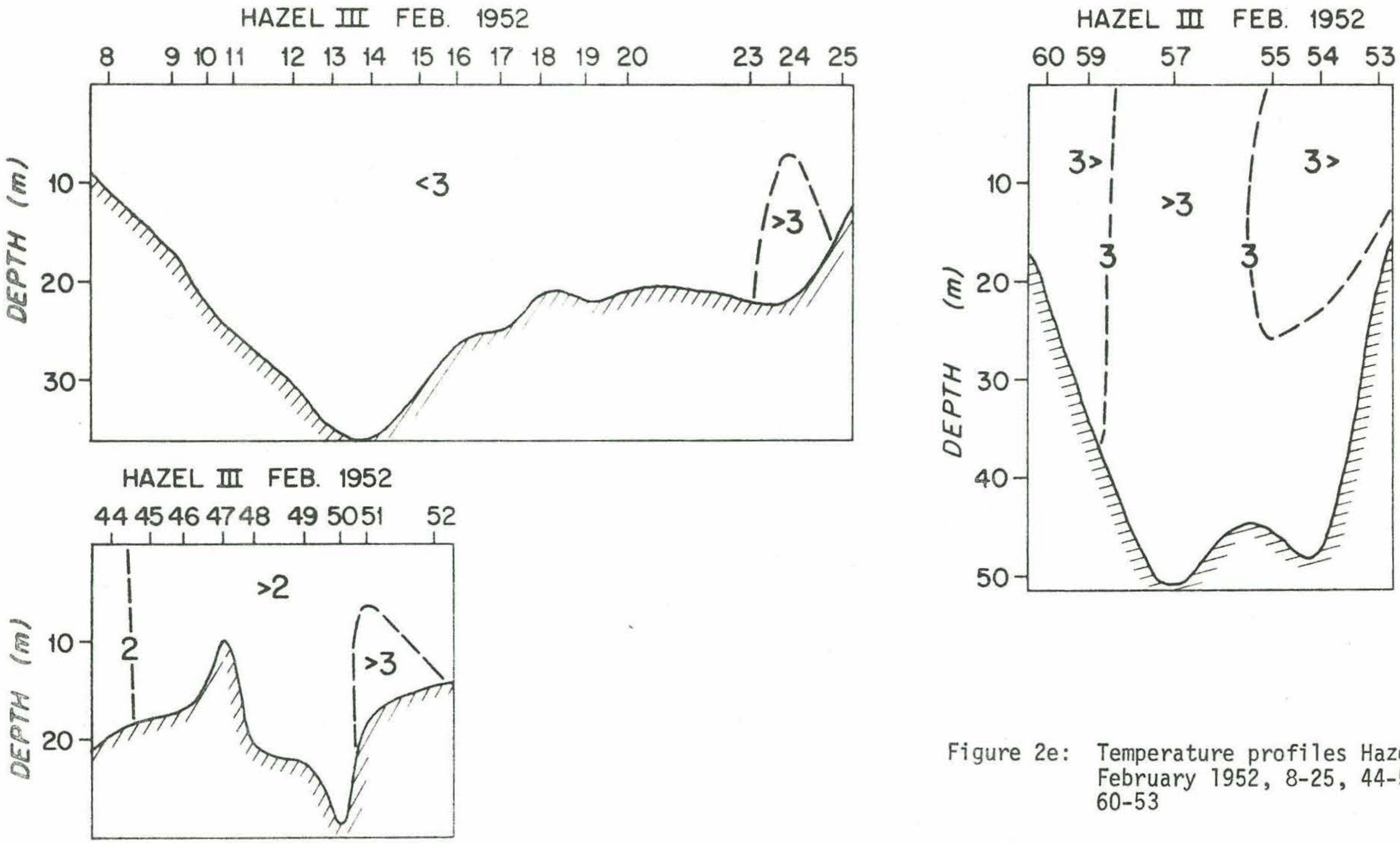


Figure 2e: Temperature profiles Hazel III February 1952, 8-25, 44-52, 60-53

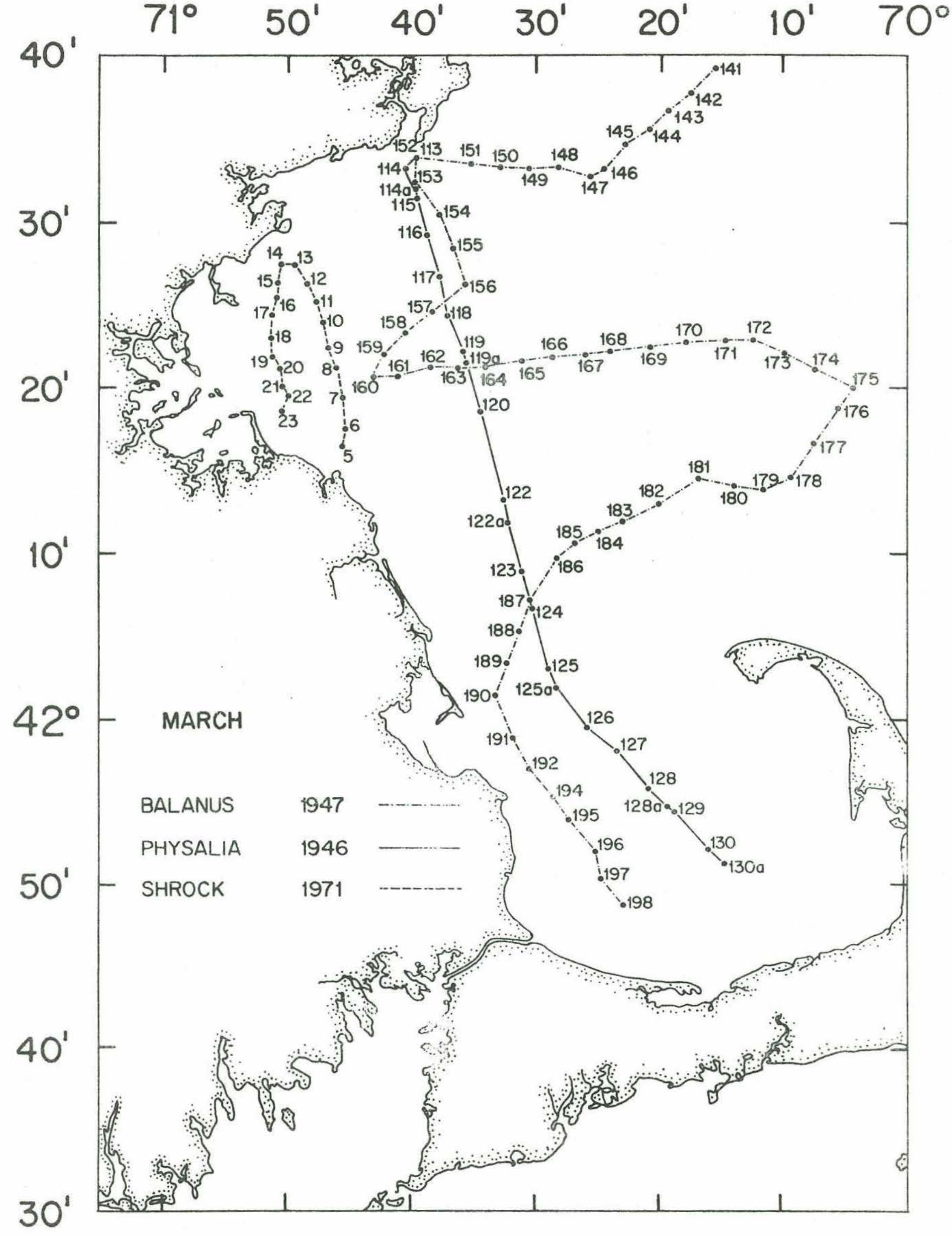
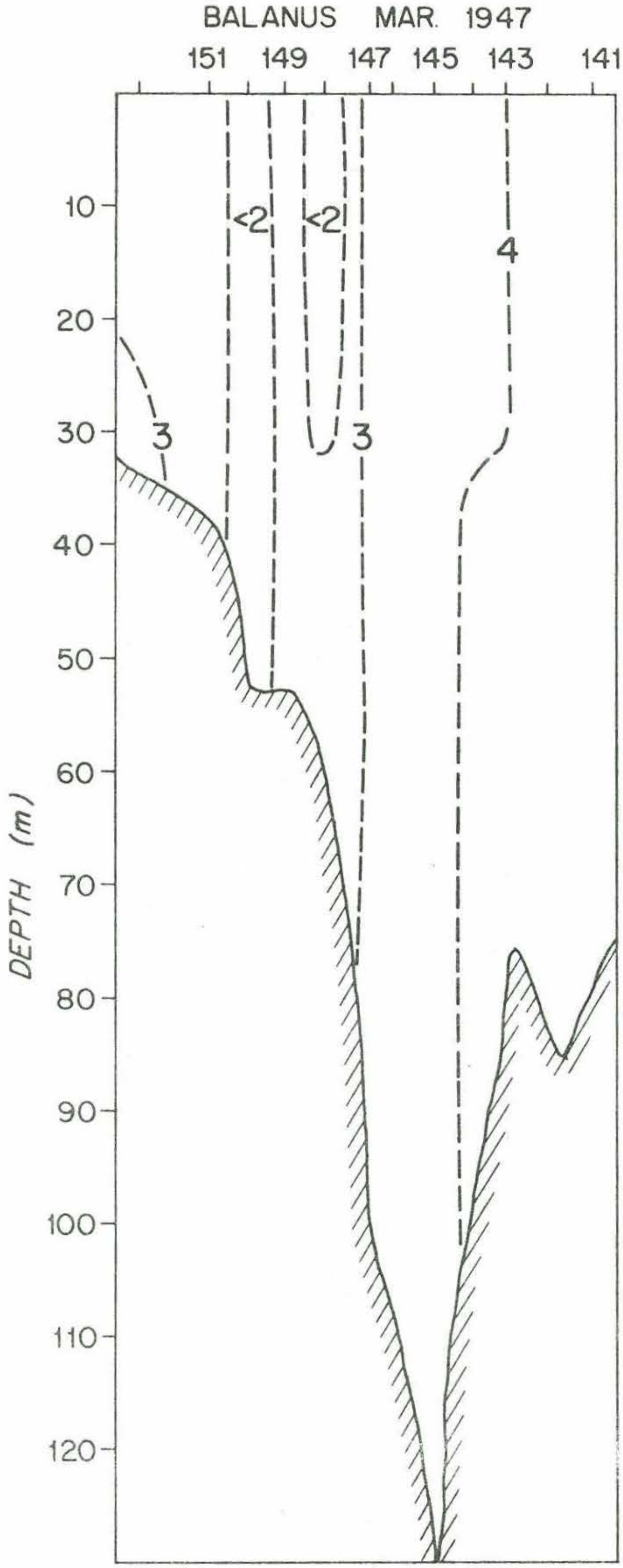


Figure 3: Location of temperature profiles for March



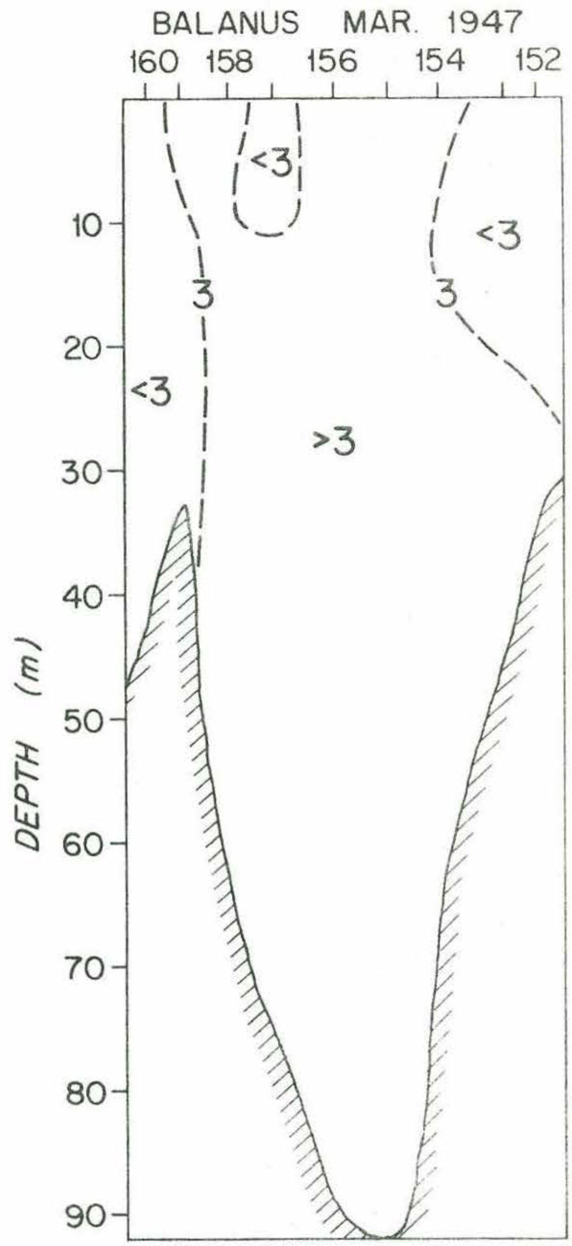


Figure 3a: Temperature profiles Balanus March 1947, 152-141, 160-152

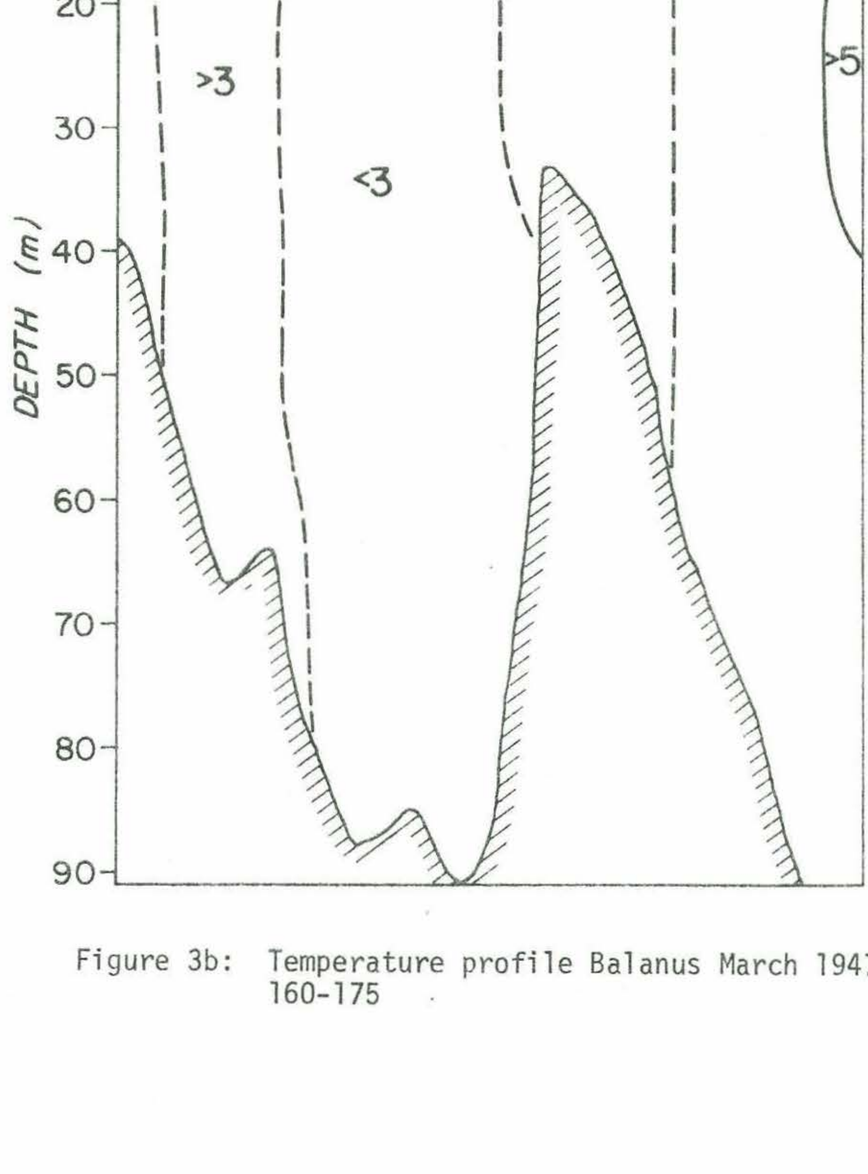


Figure 3b: Temperature profile Balanus March 1947, 160-175

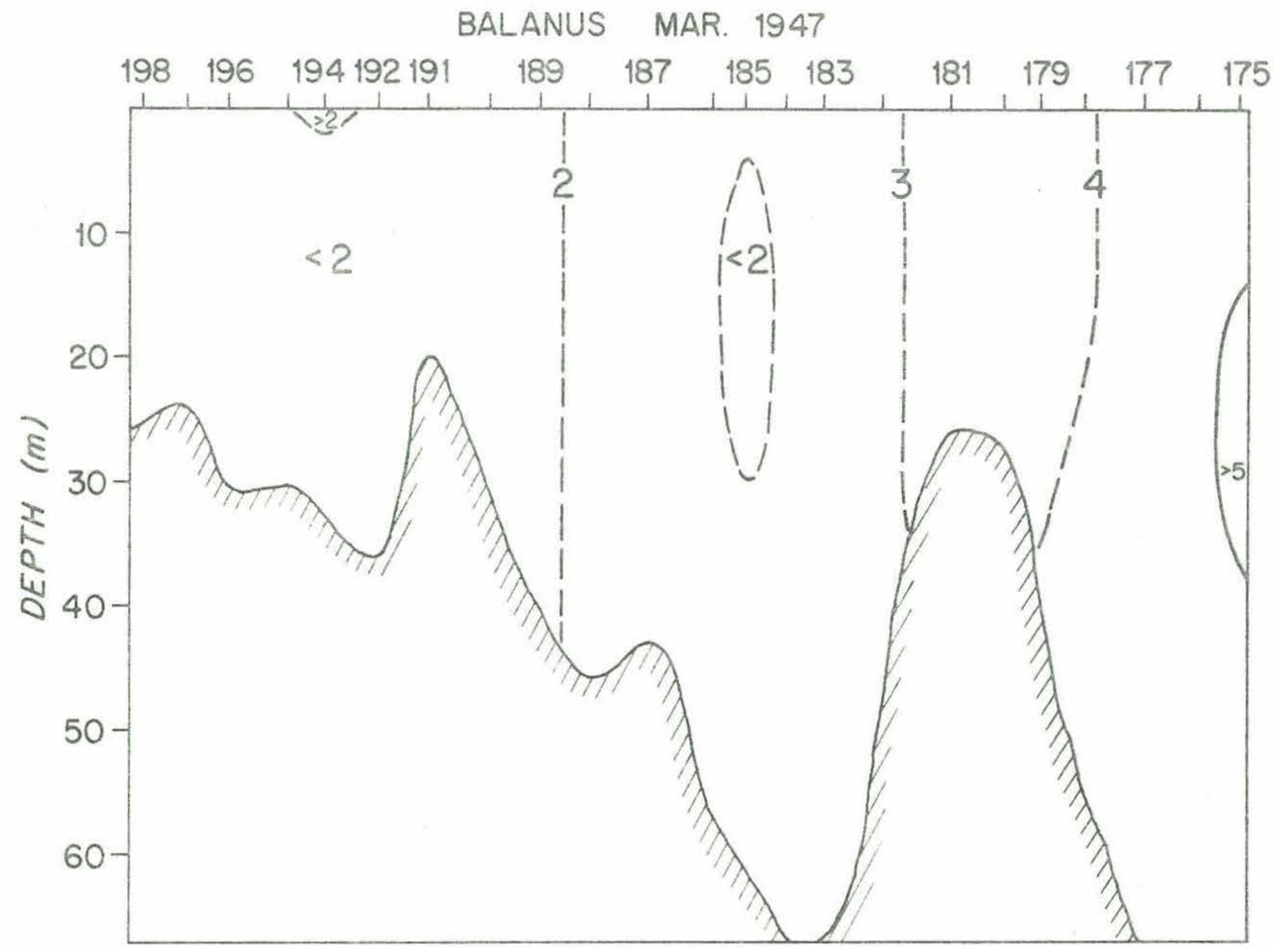


Figure 3c: Temperature profile Balanus March 1947, 198-175

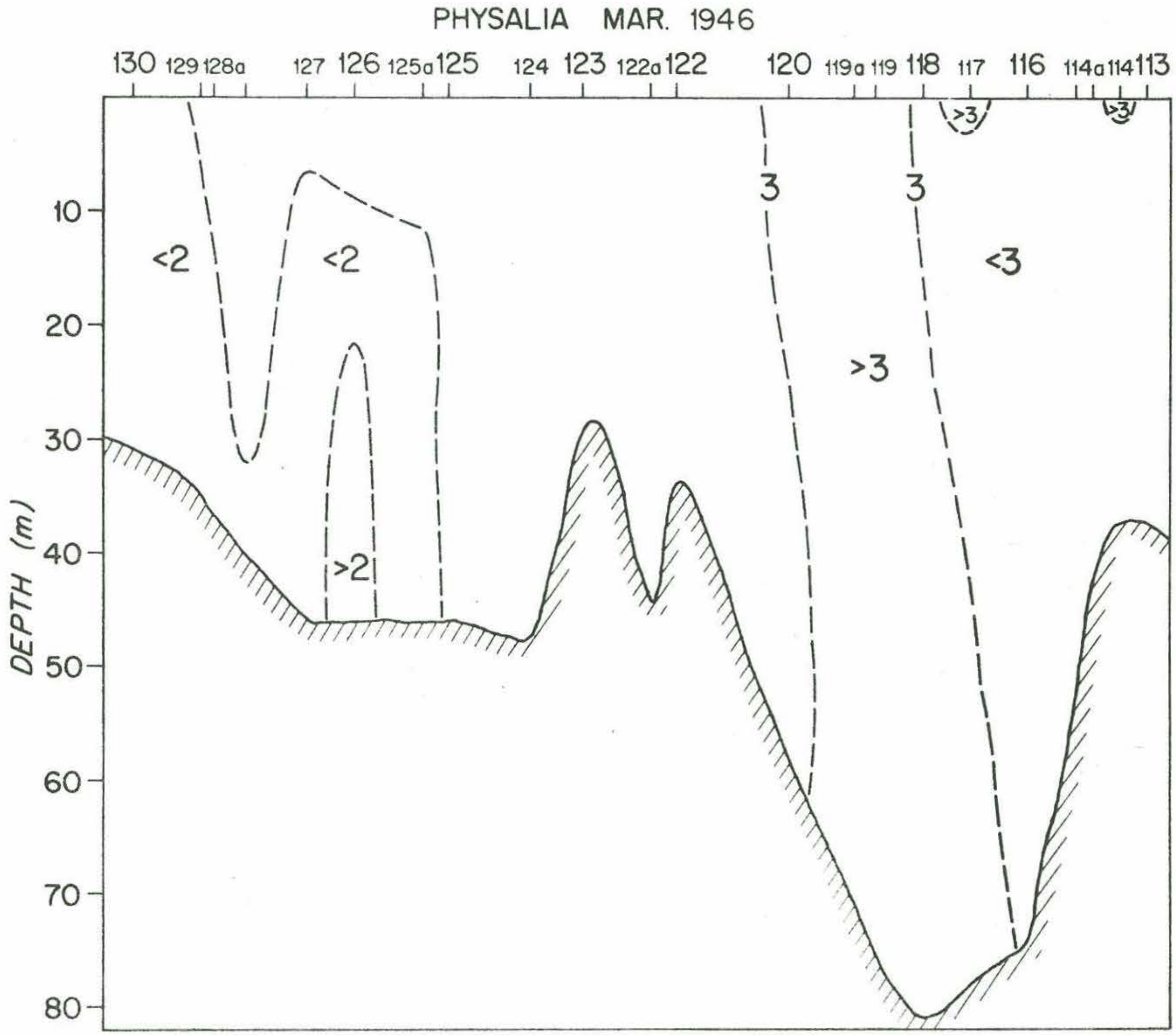
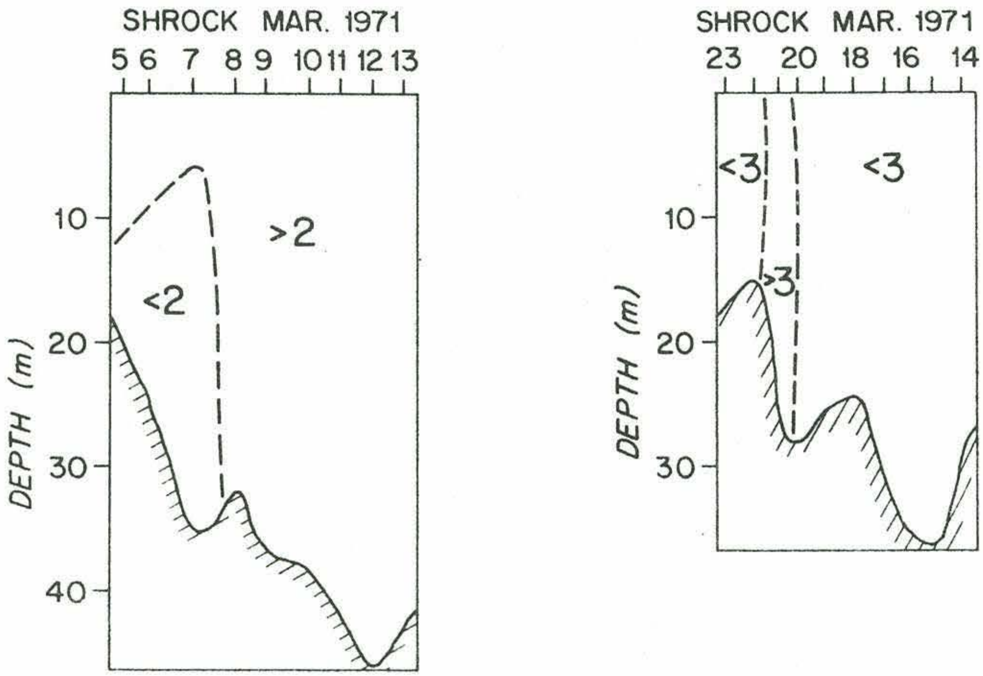


Figure 3d: Temperature profile Physalia March 1946, 130-113



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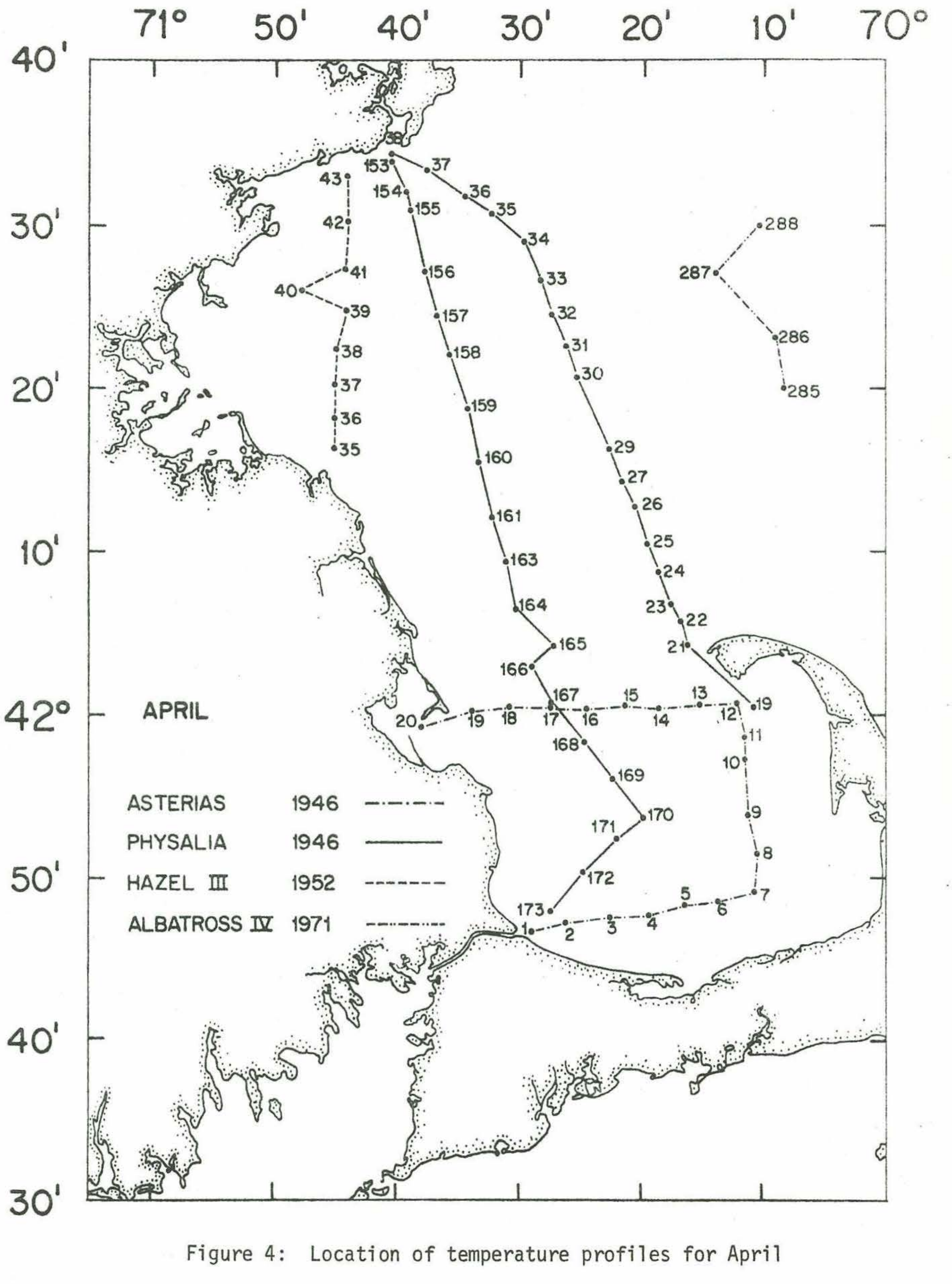


Figure 4: Location of temperature profiles for April

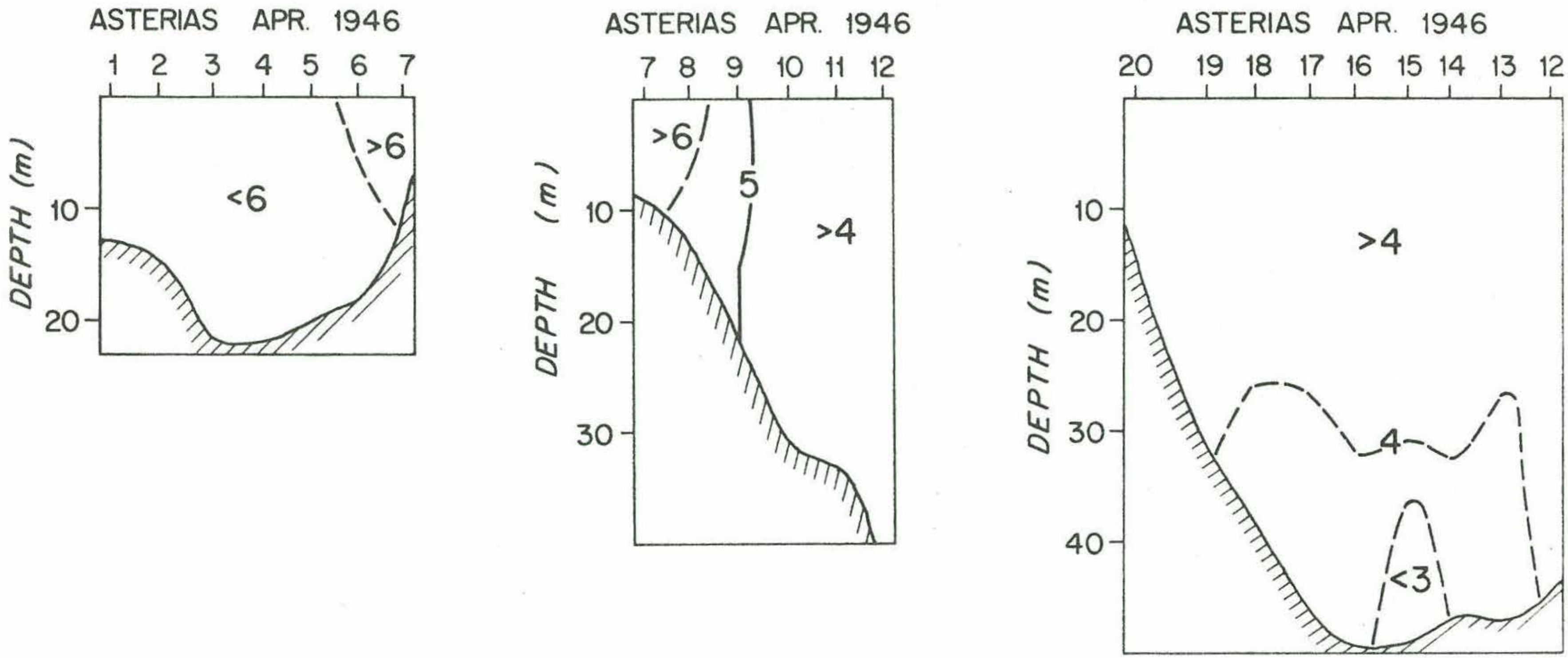


Figure 4a: Temperature profiles Asterias April 1946, 1-7, 7-12, 20-12

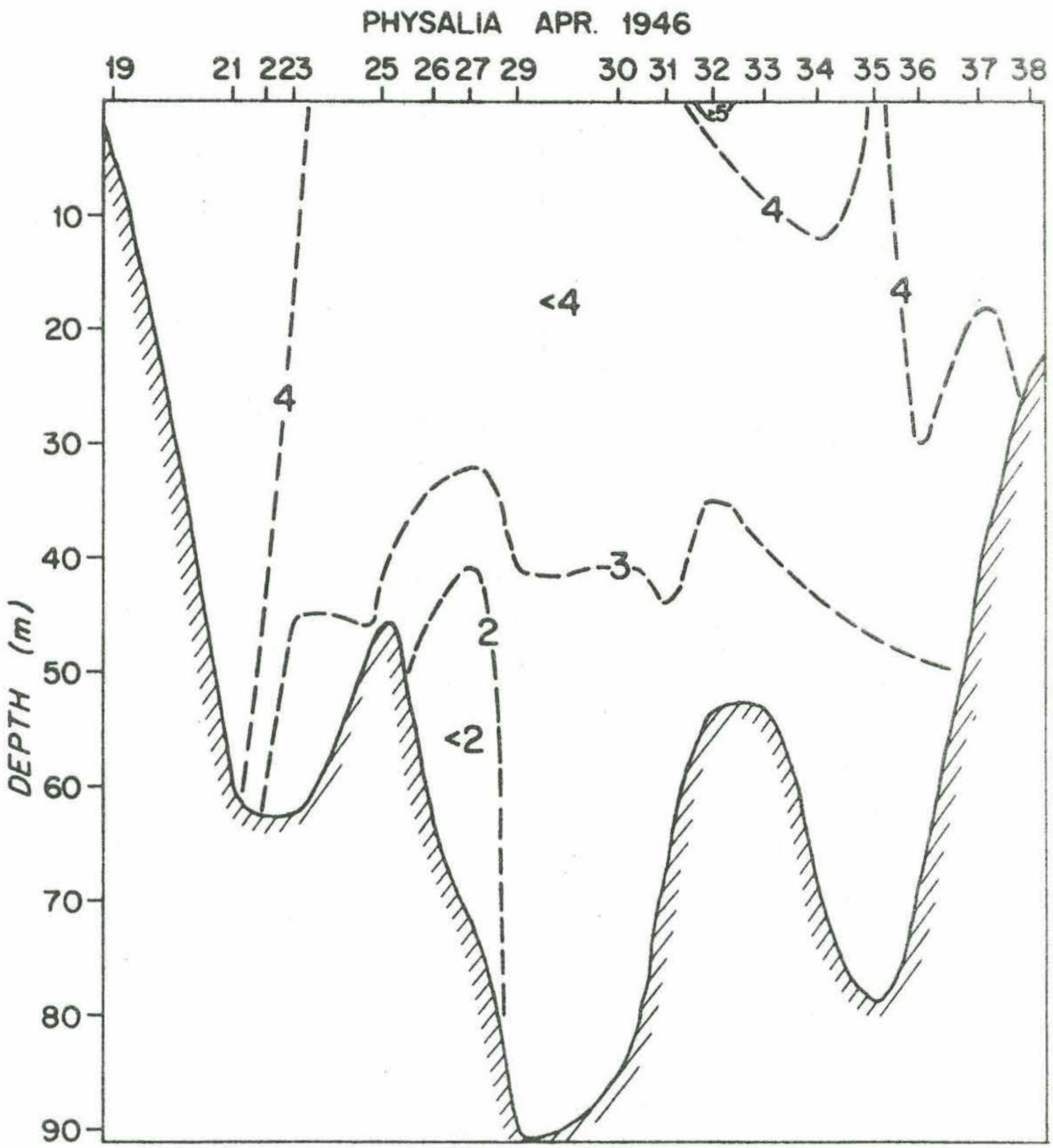


Figure 4b: Temperature profile Physalia April 1946, 19-38

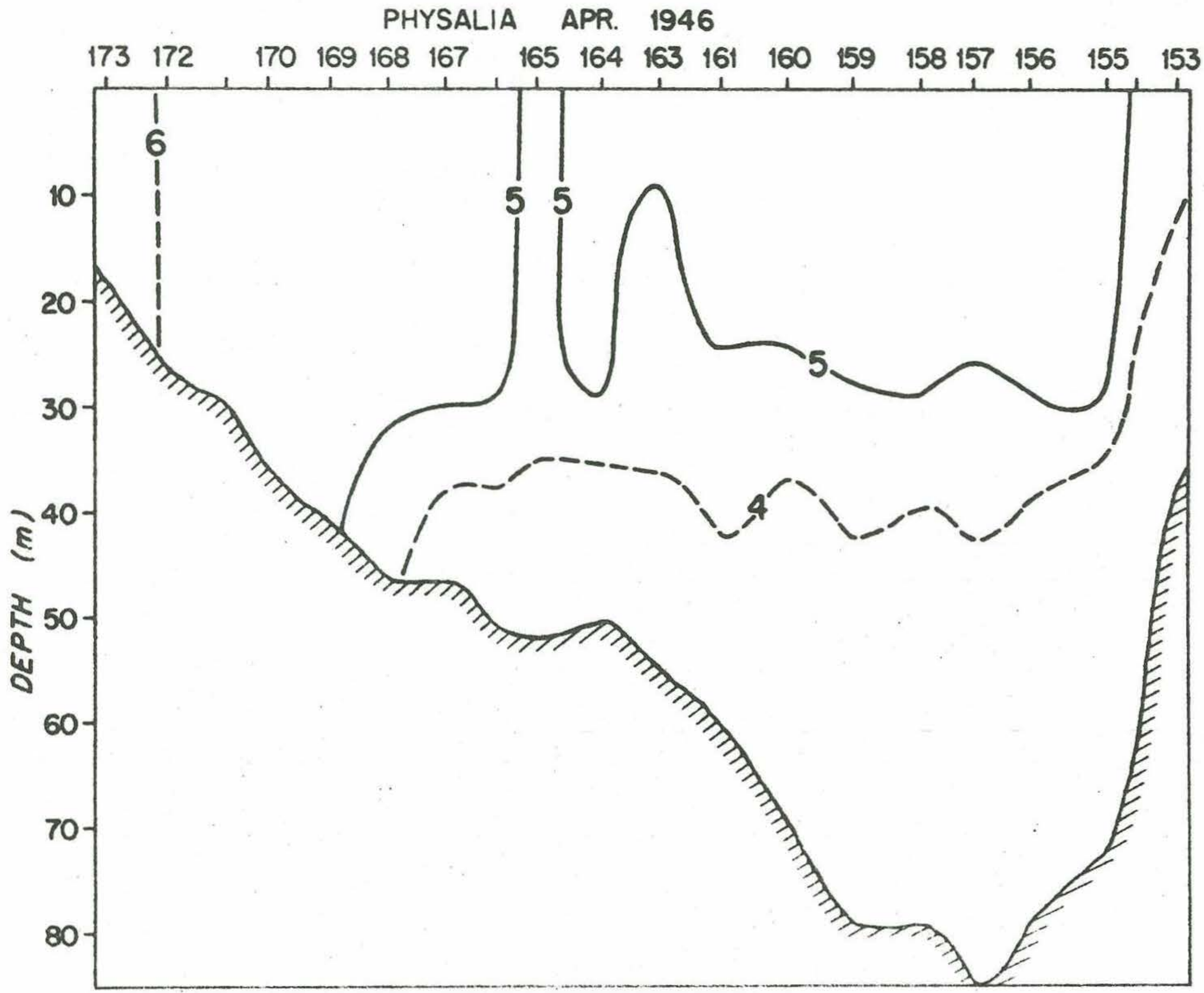


Figure 4c: Temperature profile Physalia April 1946, 173-153

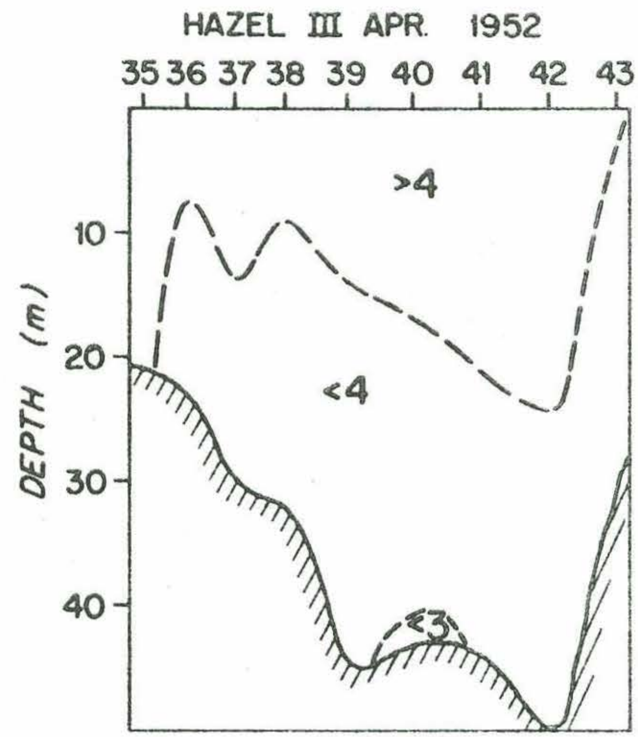


Figure 4d: Temperature profile Hazel III April 1952, 35-43

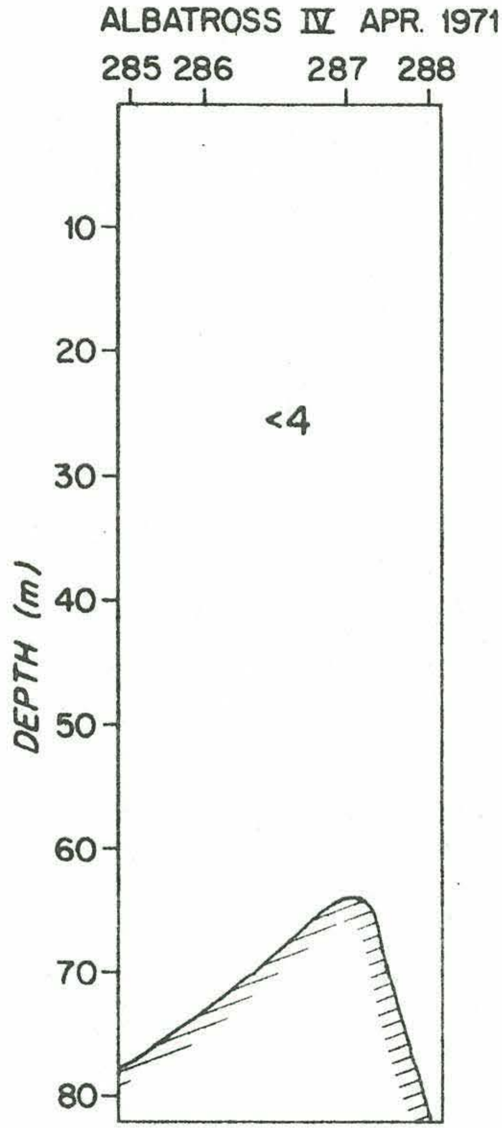


Figure 4e: Temperature profile Albatross IV April 1971, 285-288

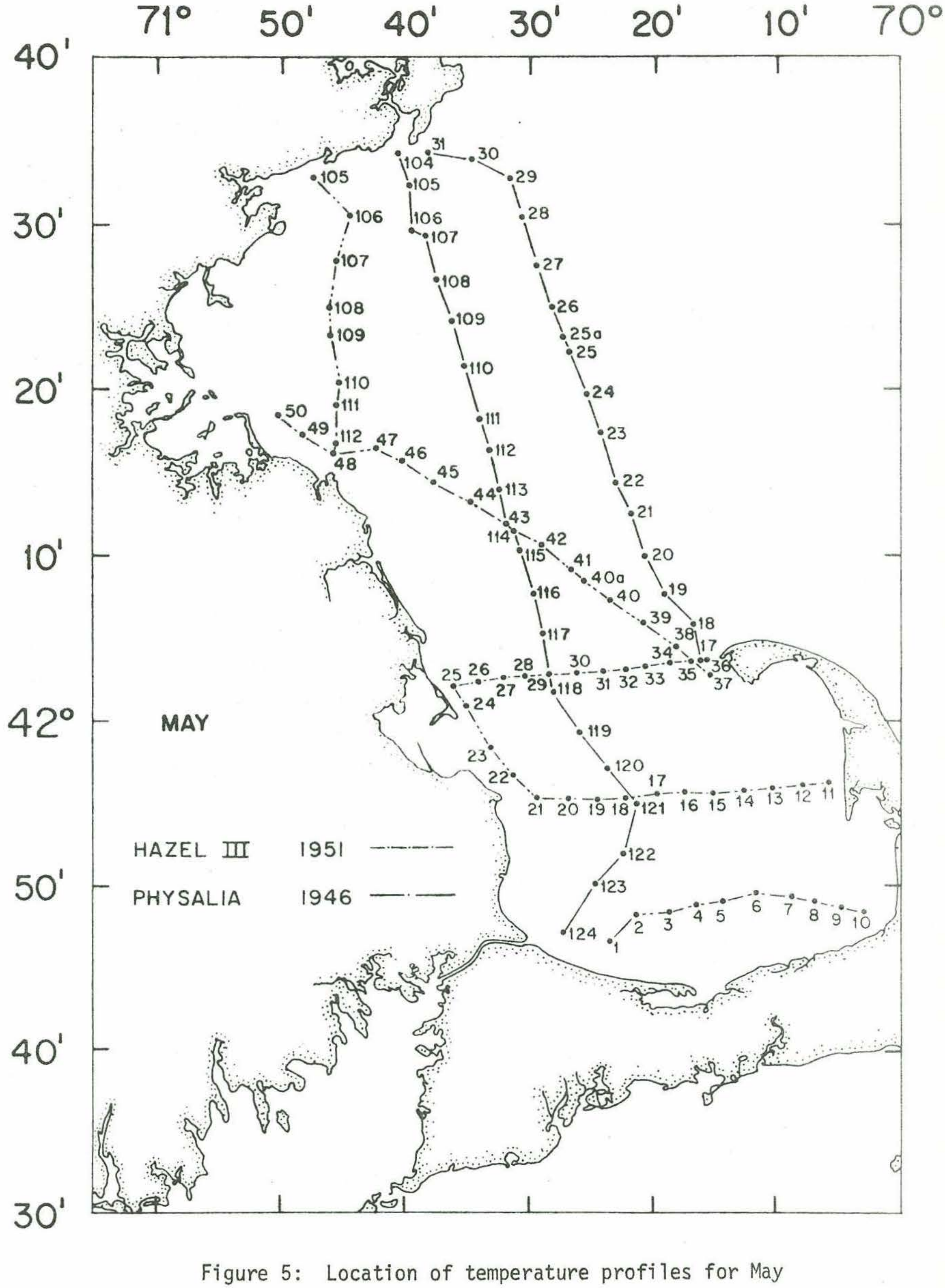


Figure 5: Location of temperature profiles for May

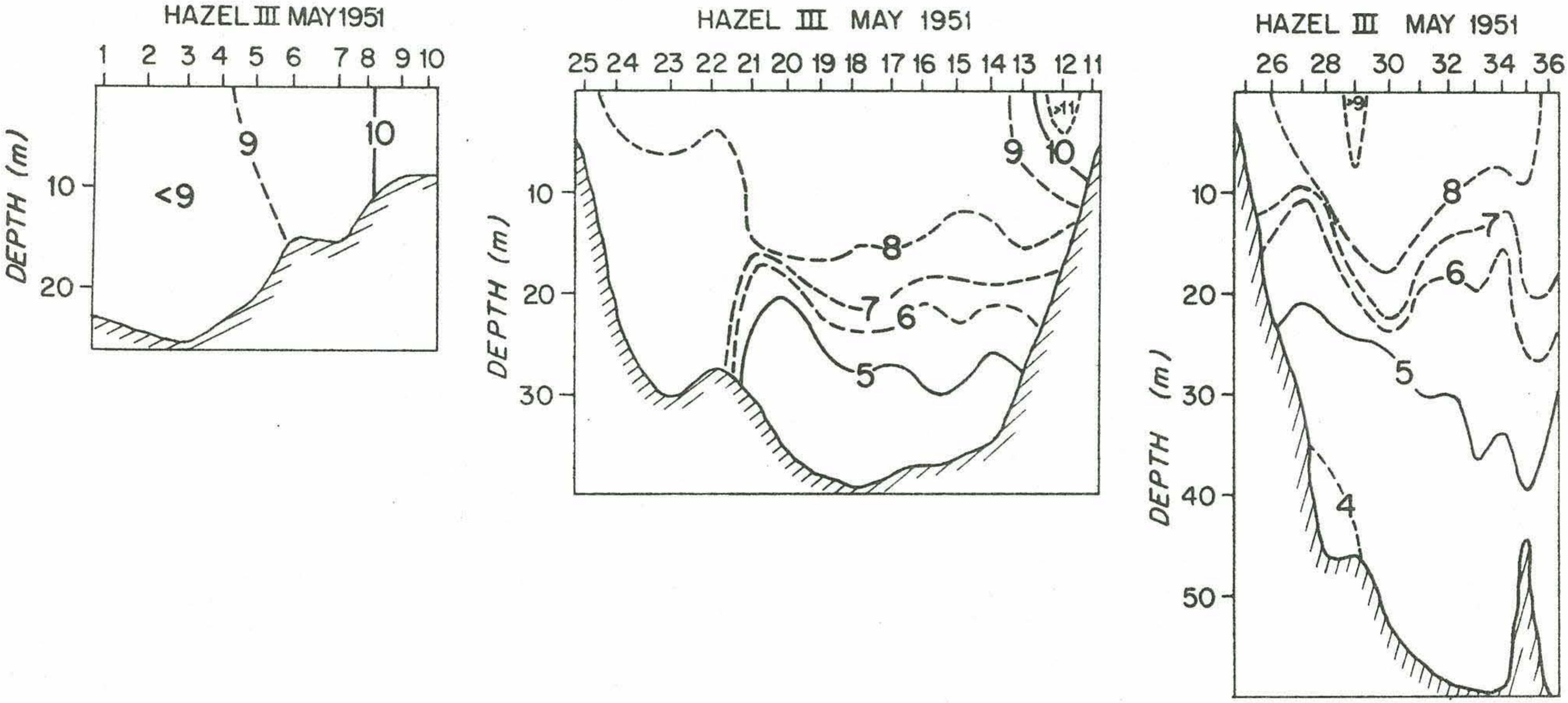


Figure 5a: Temperature profiles Hazel III May 1951, 1-10, 25-11, 26-36

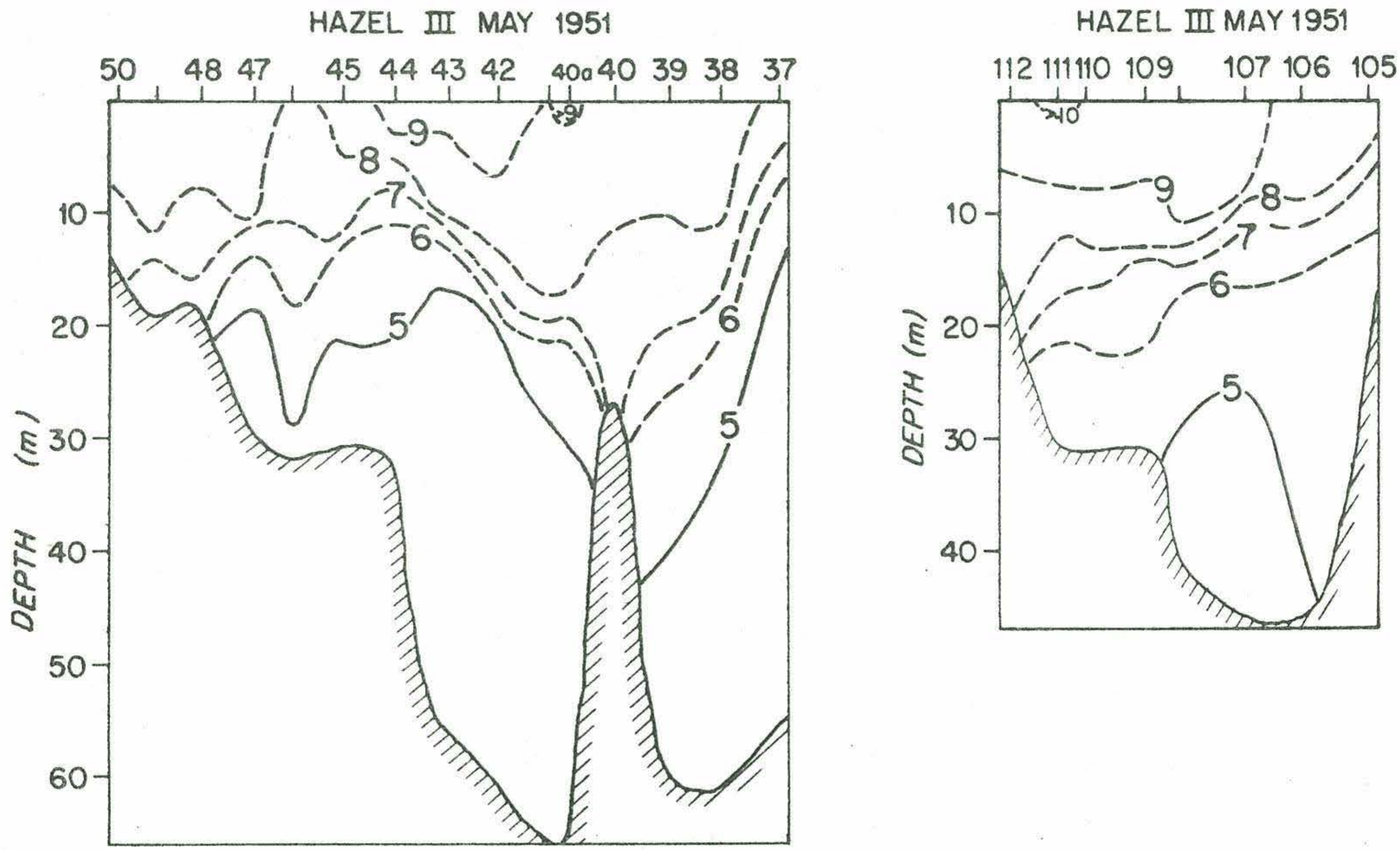


Figure 5b: Temperature profiles Hazel III May 1951
50-37, 112-105

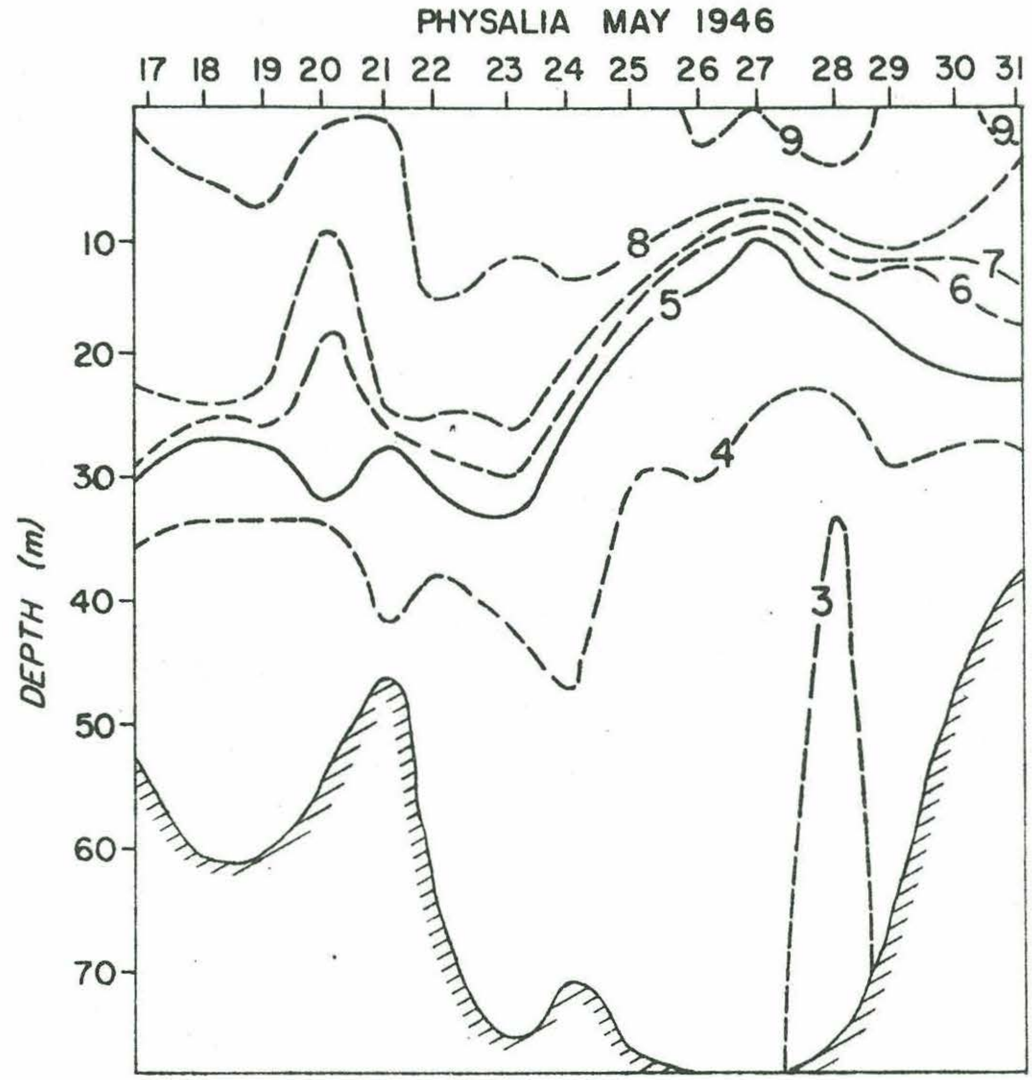


Figure 5c: Temperature profile Physalia May 1946, 17-31

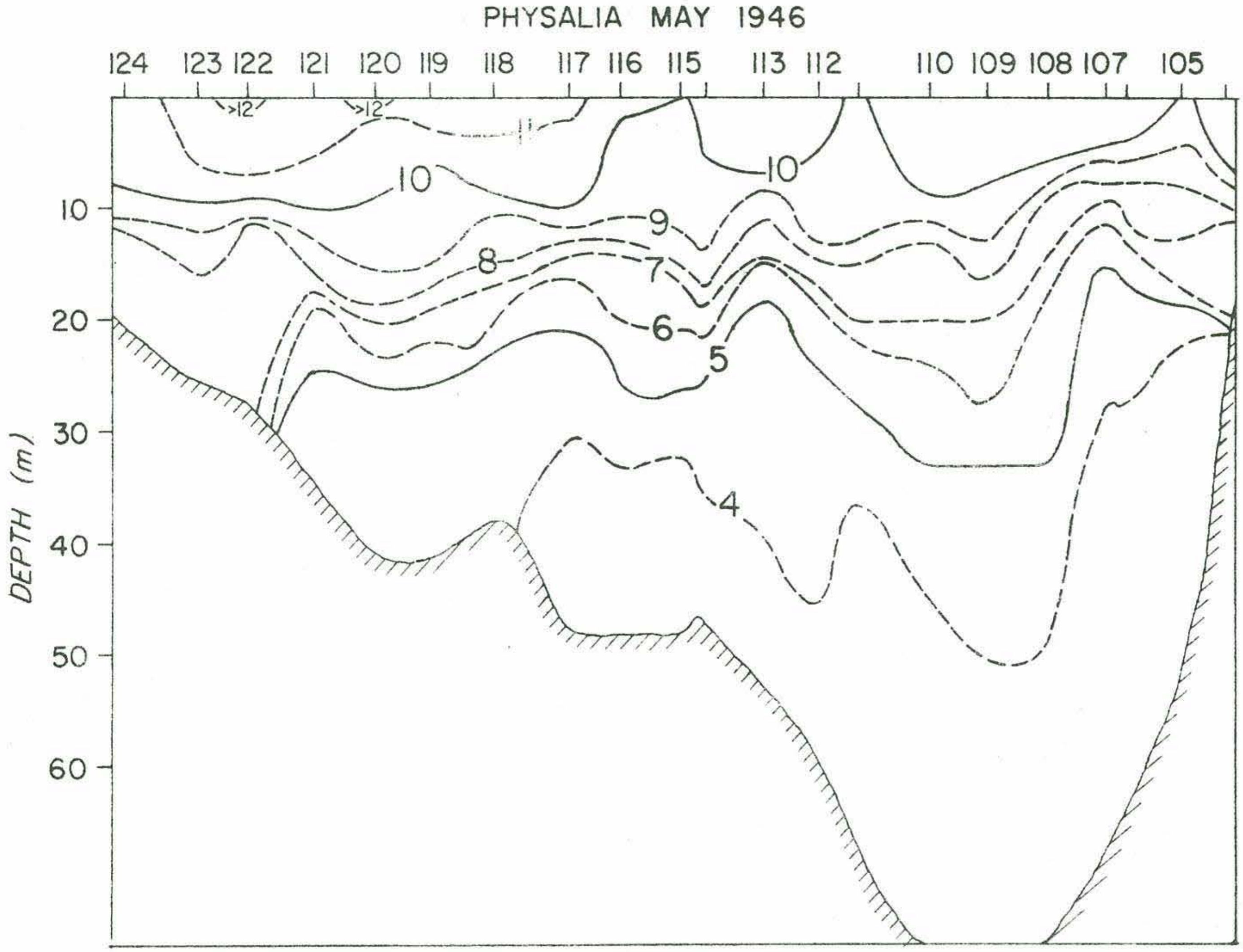


Figure 5d: Temperature profile Physalia May 1946, 124-104

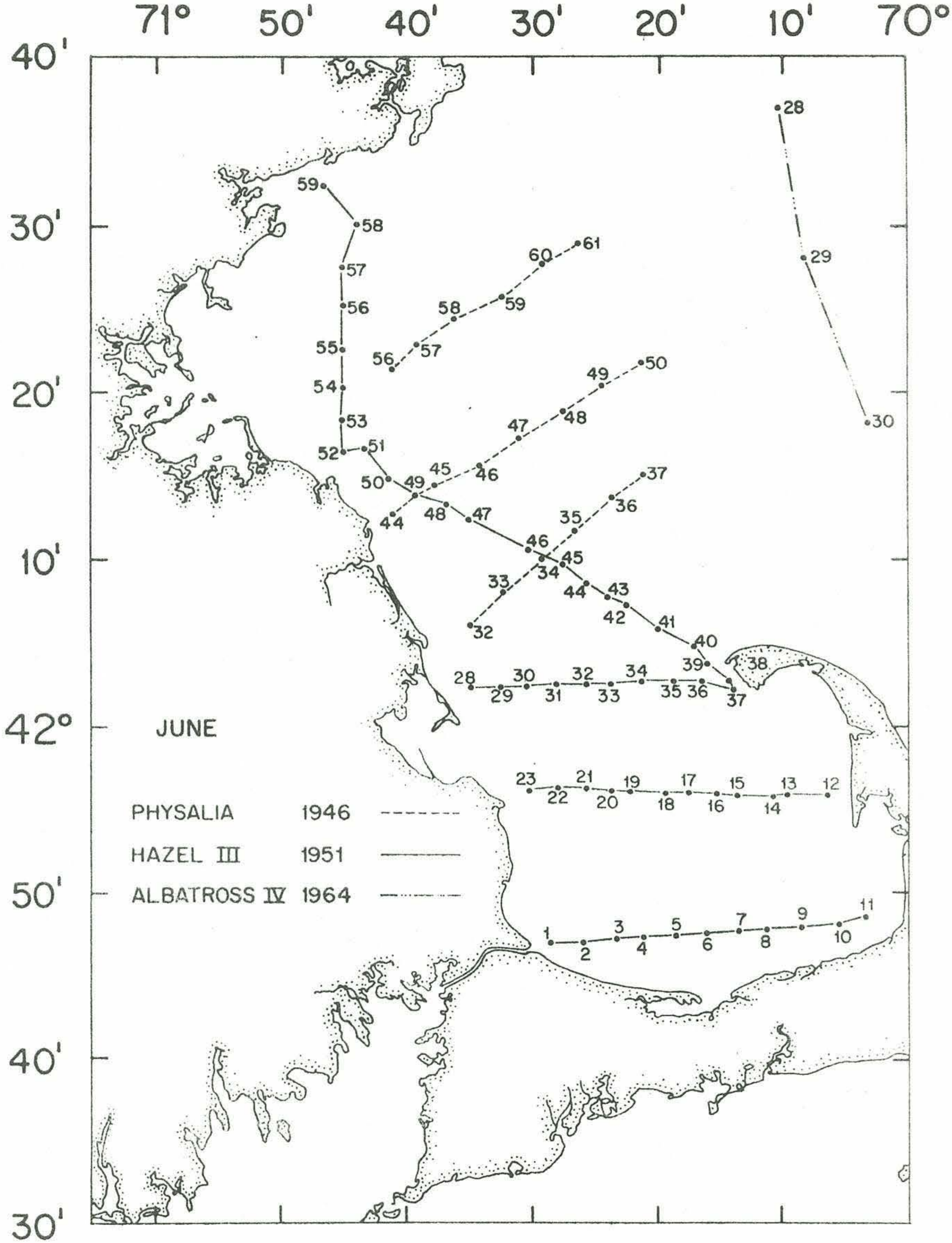


Figure 6: Location of temperatures profiles for June

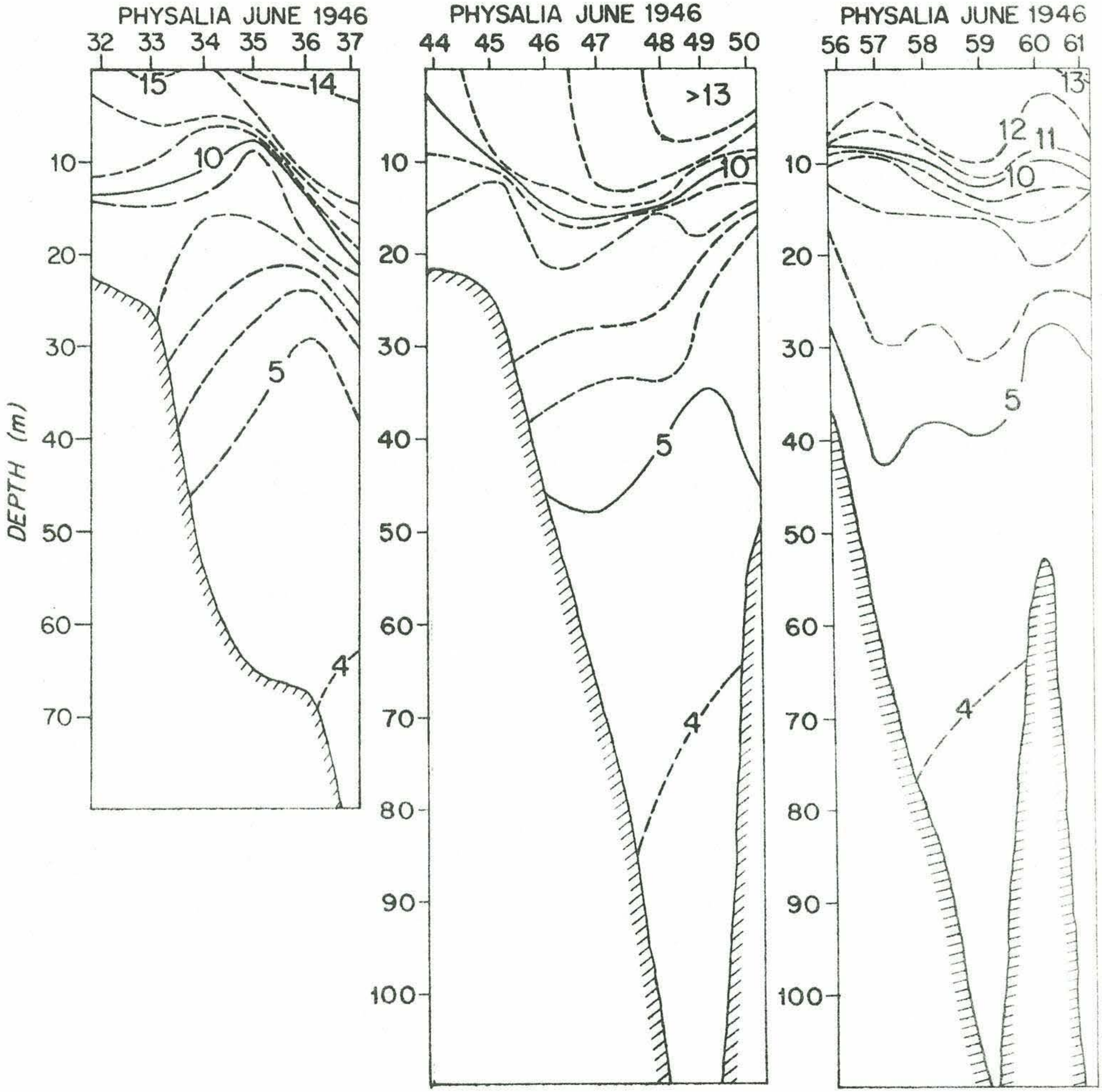


Figure 6a: Temperature profile Physalia June 1946, 32-37, 44-50, 56-61

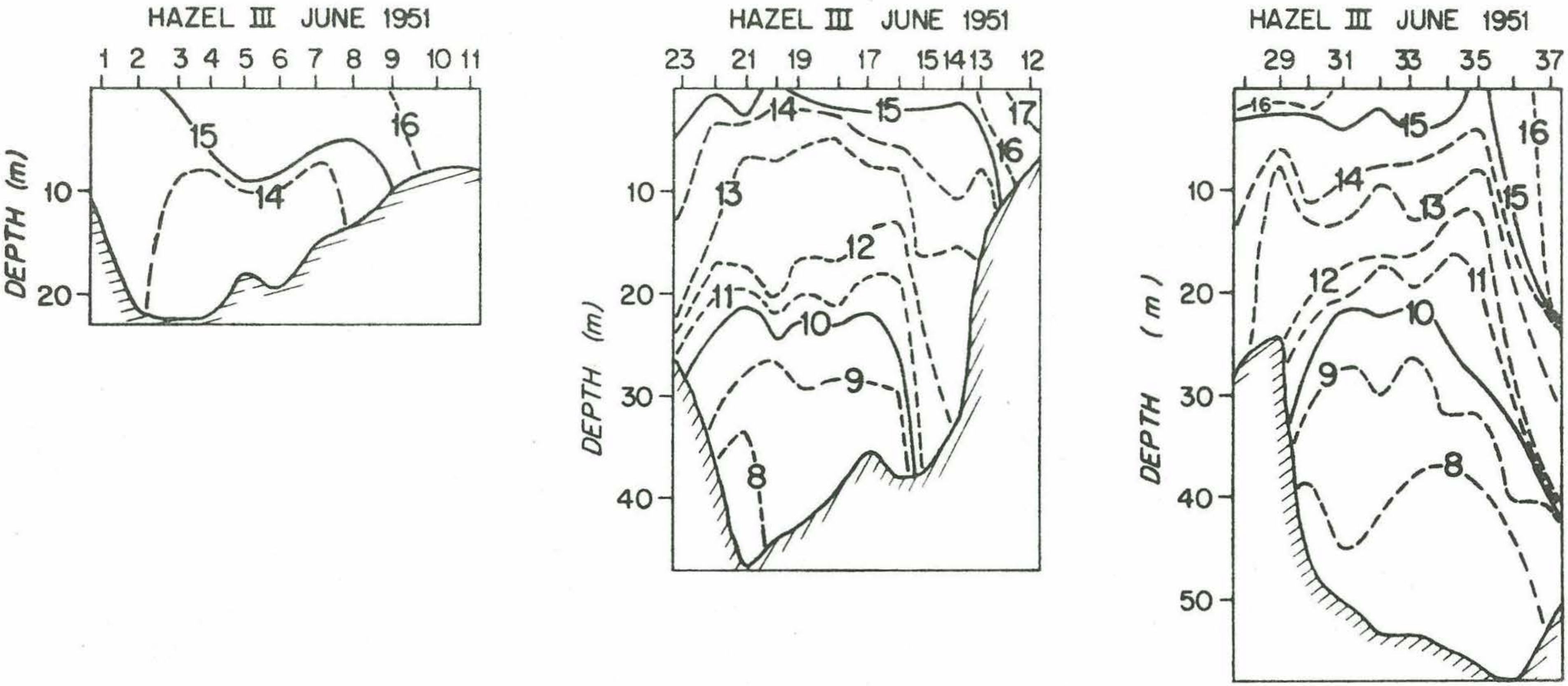
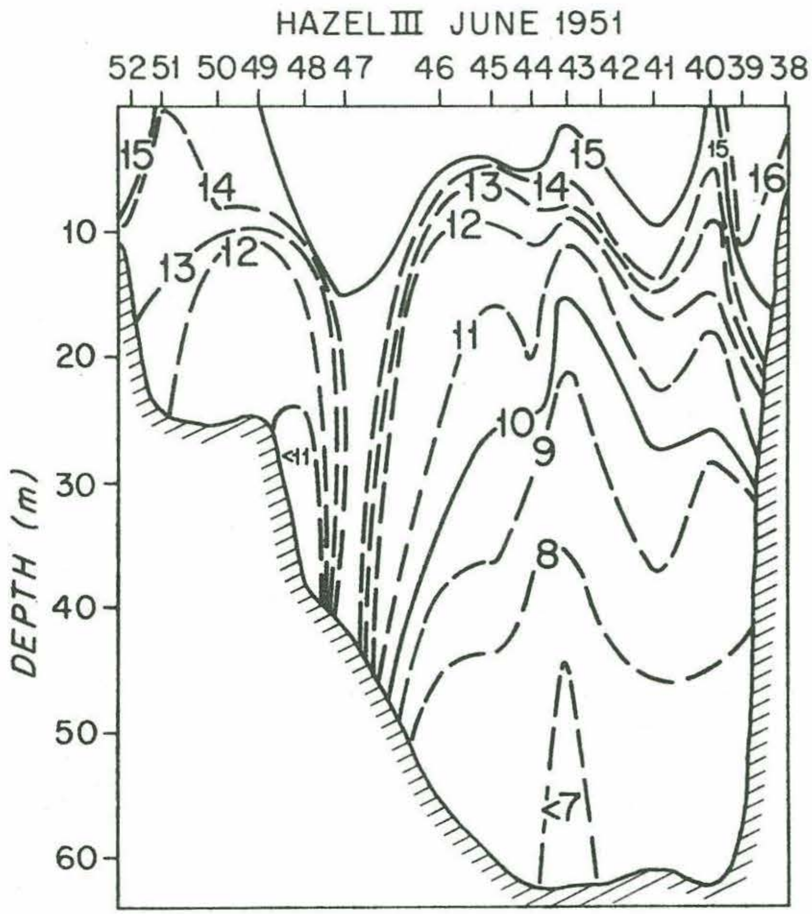


Figure 6b: Temperature profiles Hazel III June 1951, 1-11, 23-12, 28-37



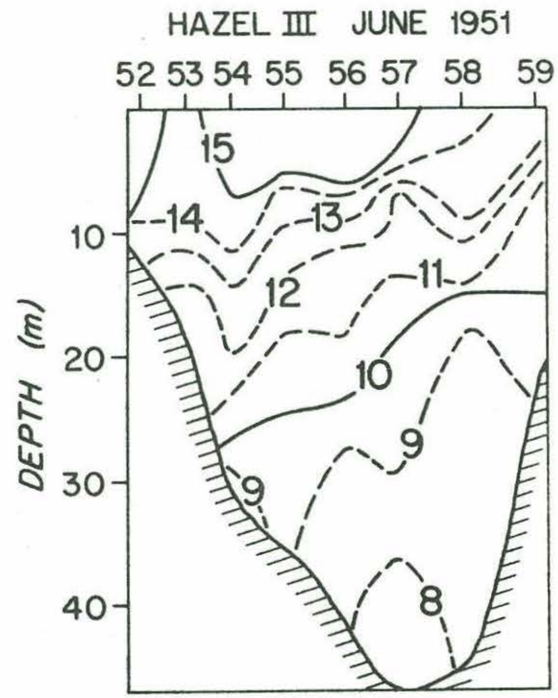


Figure 6c: Temperature profiles
Hazel III June 1951
52-38, 52-59

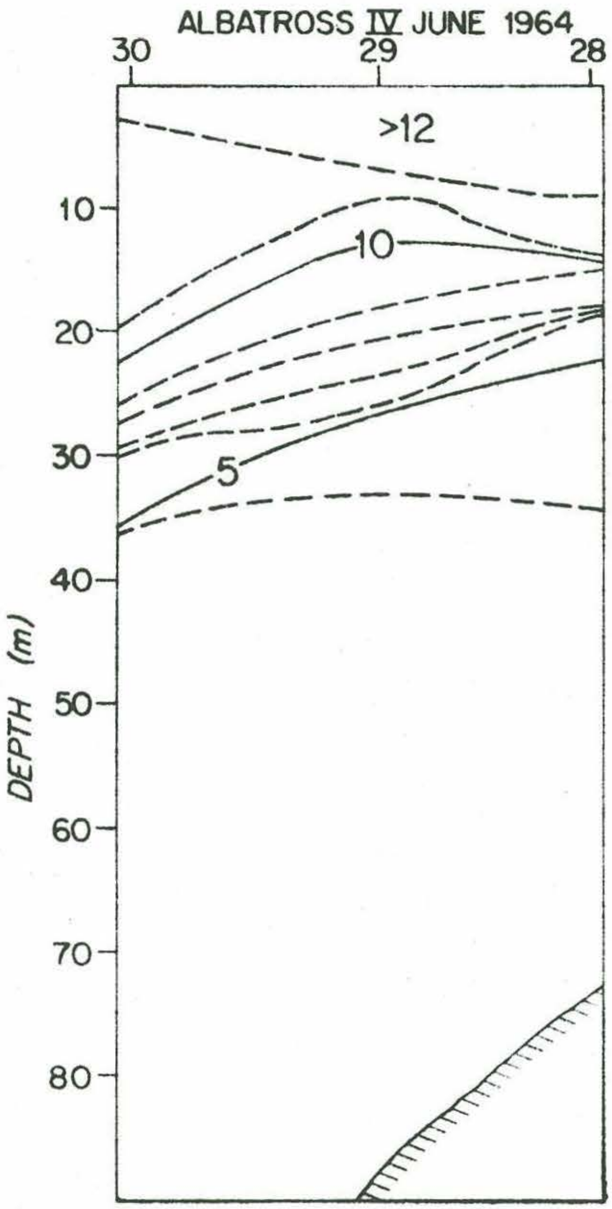


Figure 6d: Temperature profile Albatross IV June 1964, 30-28

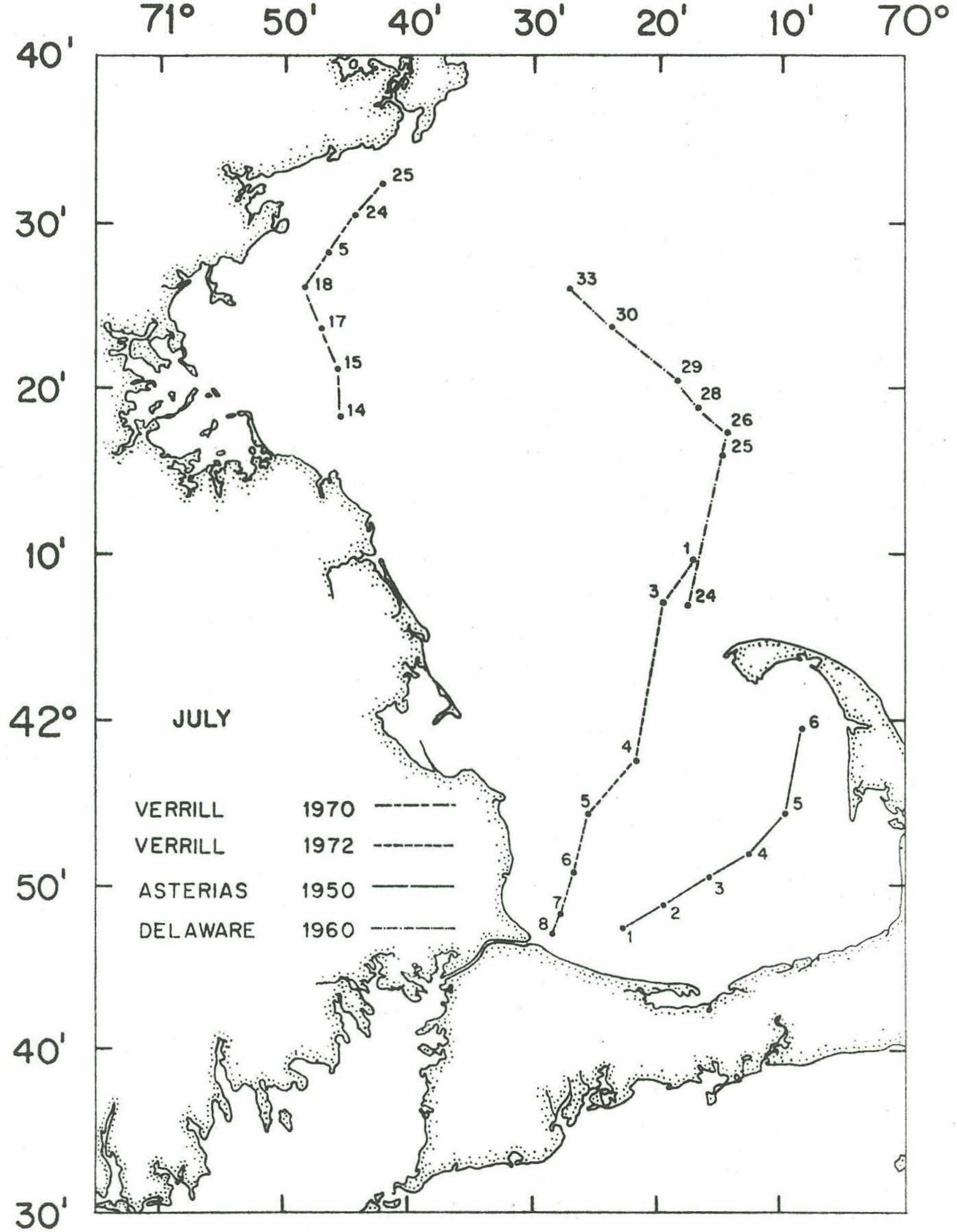


Figure 7: Location of temperature profiles for July

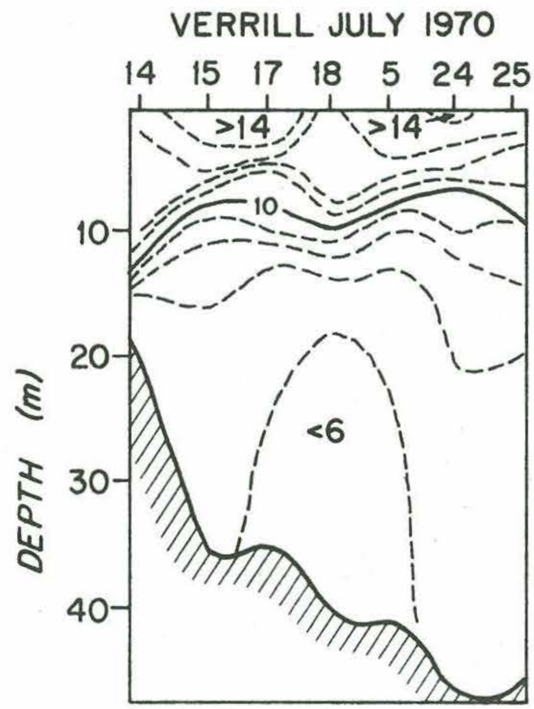


Figure 7a: Temperature profile Verrill July 1970, 14-25

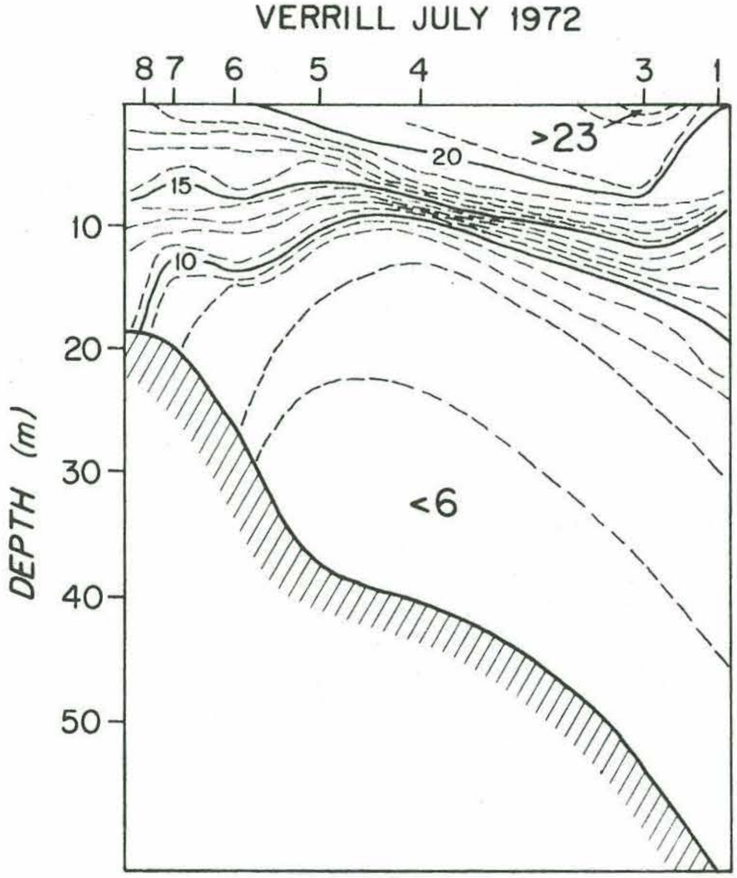


Figure 7b: Temperature profile Verrill July 1972, 8-1

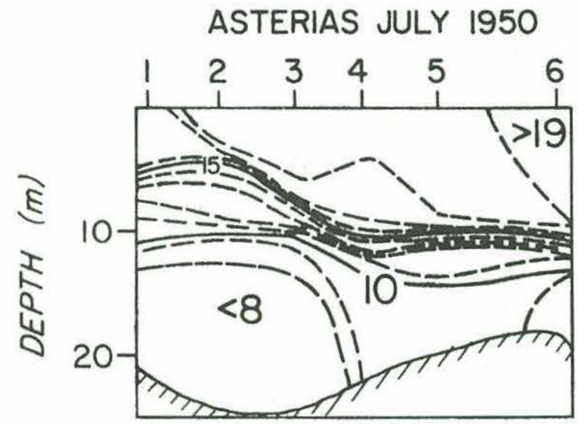


Figure 7c: Temperature profile Asterias July 1950, 1-6

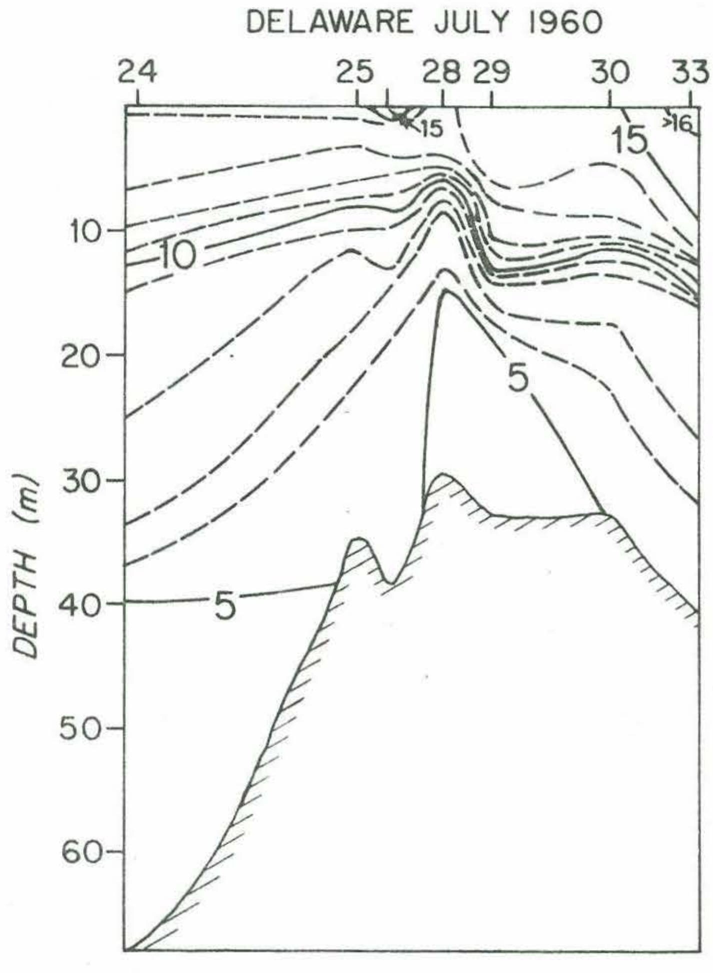


Figure 7d: Temperature profile Delaware July 1960, 24-33

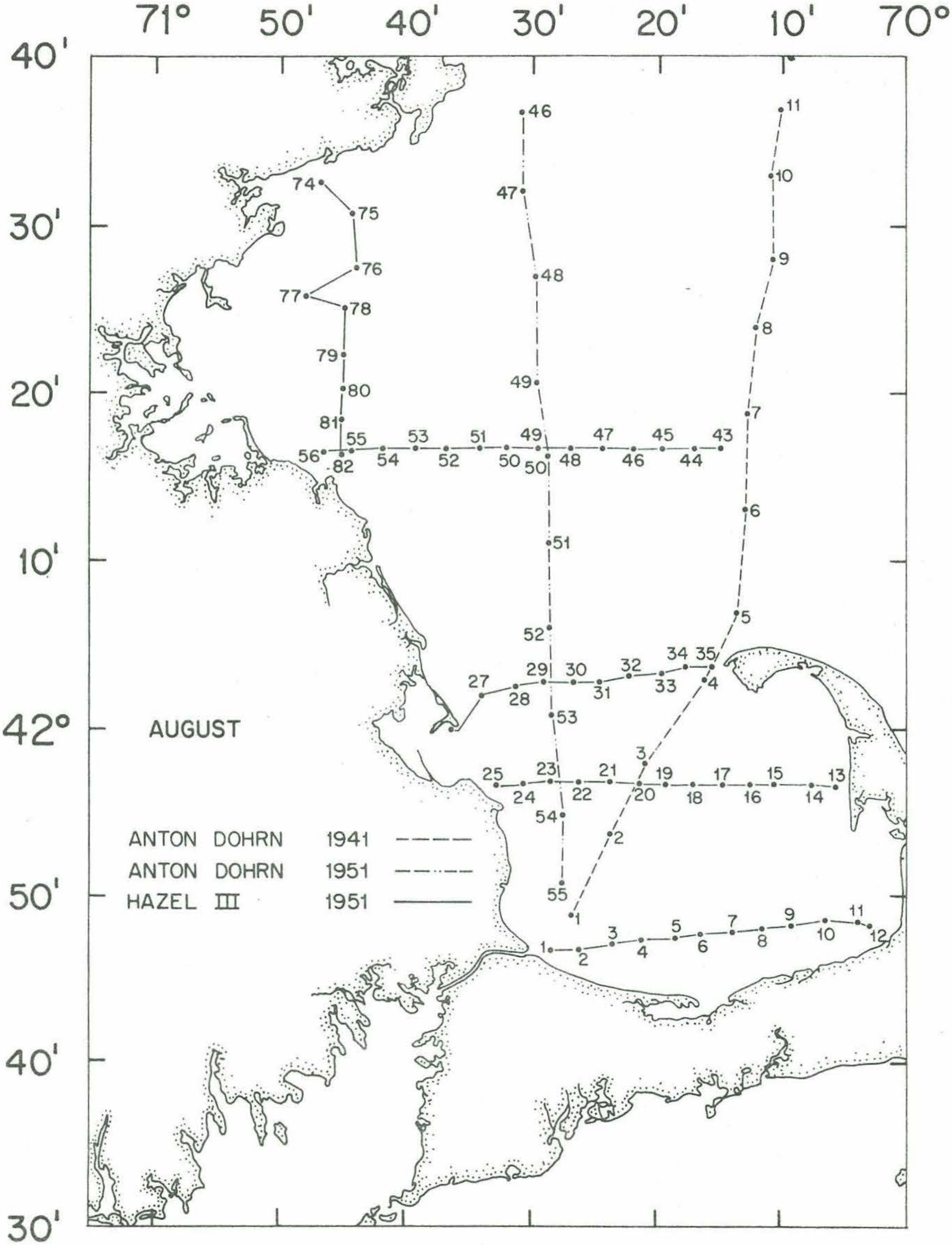


Figure 8: Location of temperature profiles for August

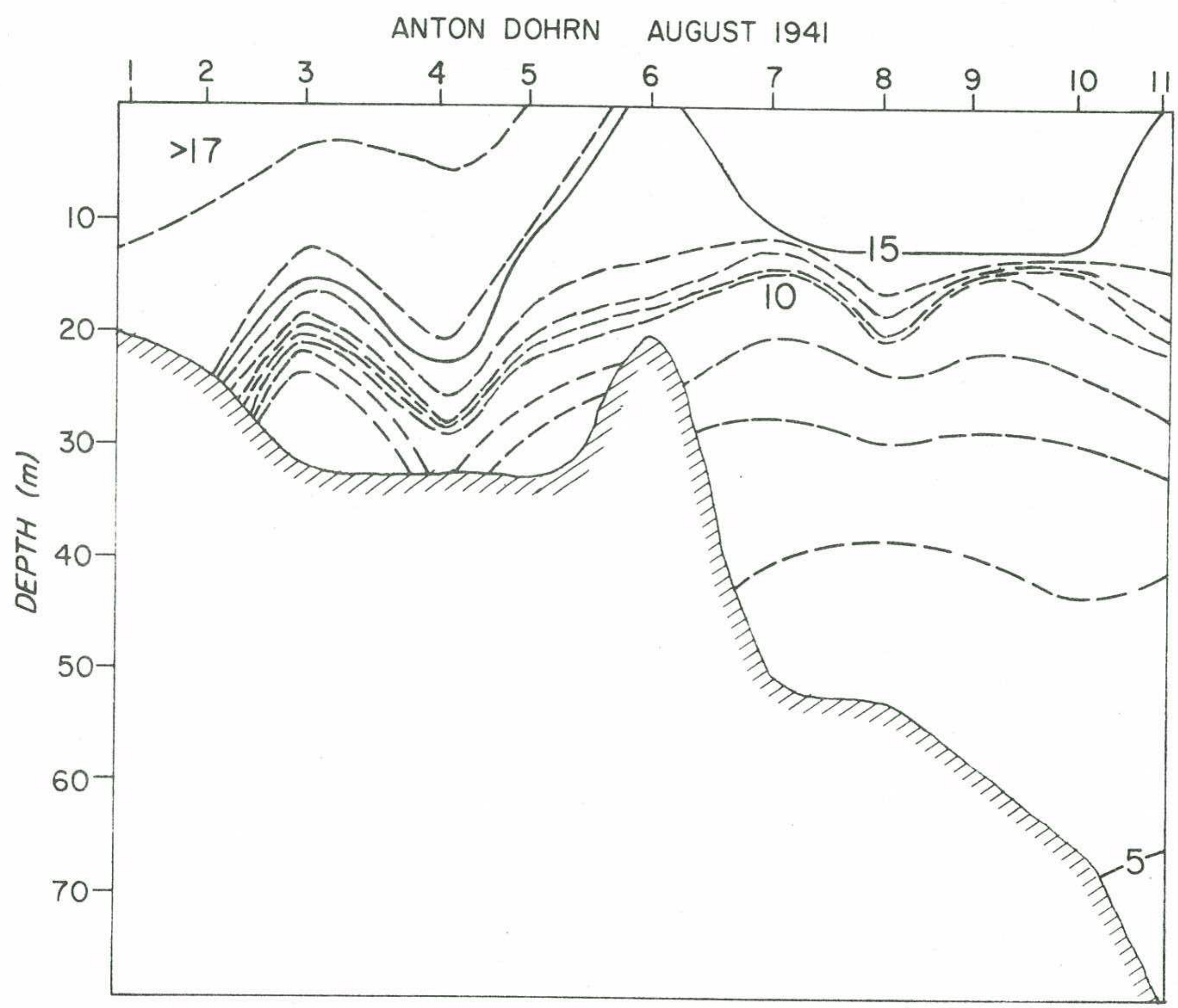


Figure 8a: Temperature profile Anton Dohrn August 1941, 1-11

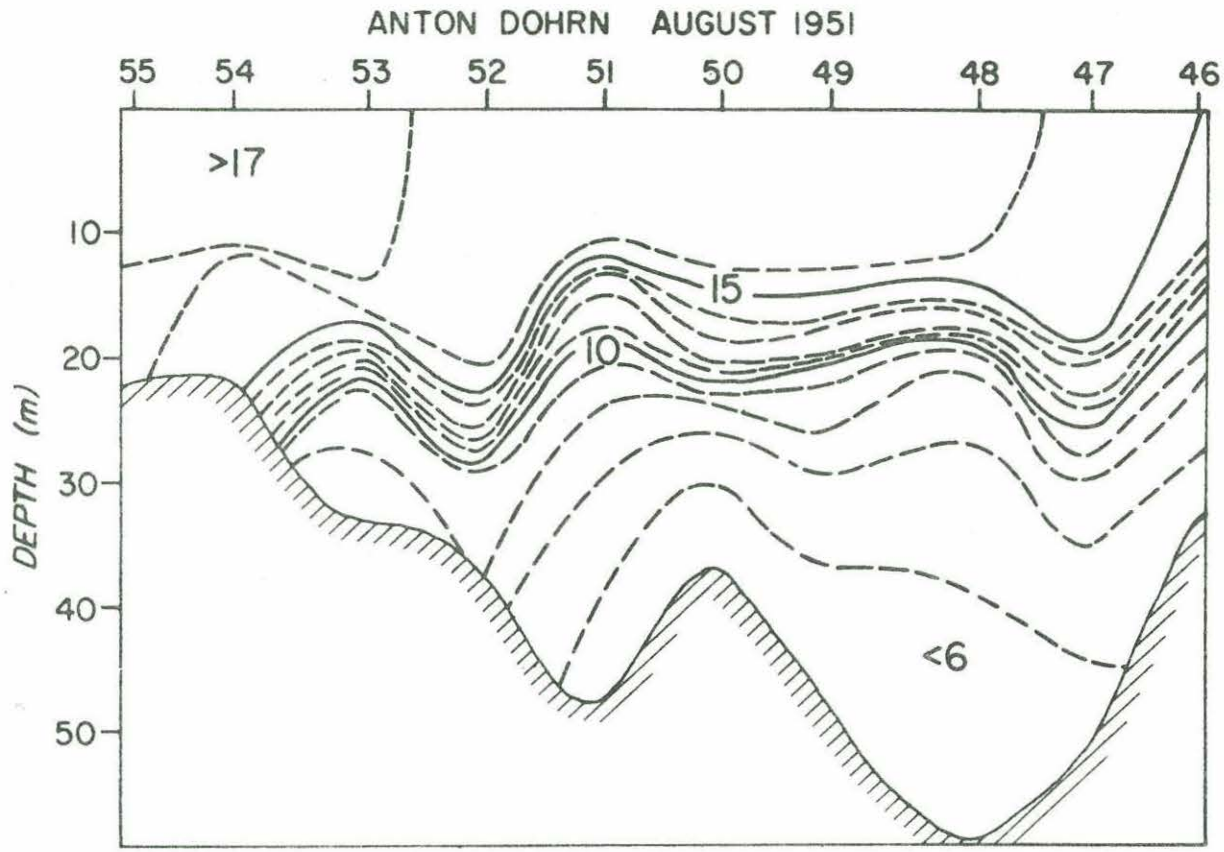


Figure 8b: Temperature profile Anton Dohrn August 1951, 55-46

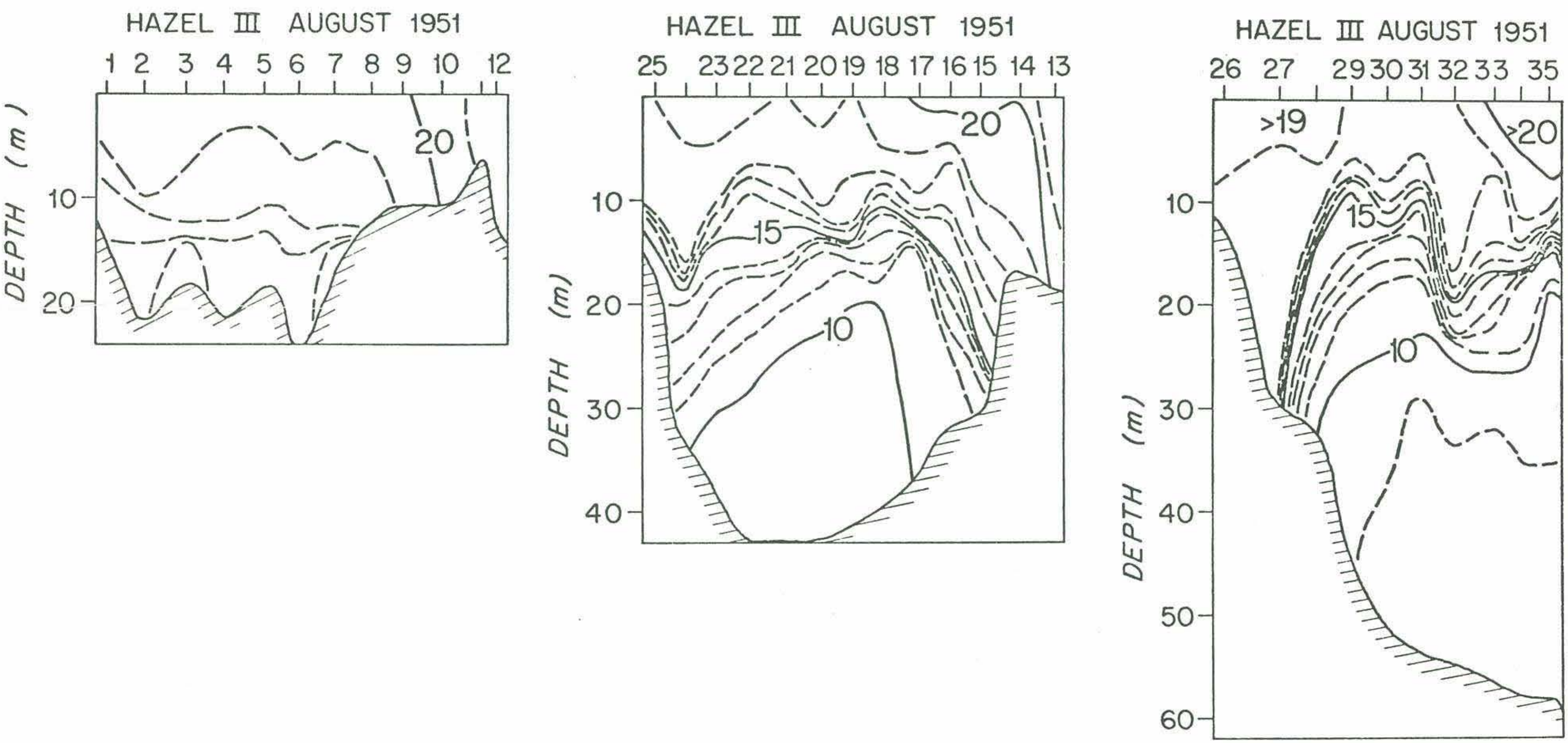


Figure 8c: Temperature profiles Hazel III August 1951, 1-12, 25-13, 26-53

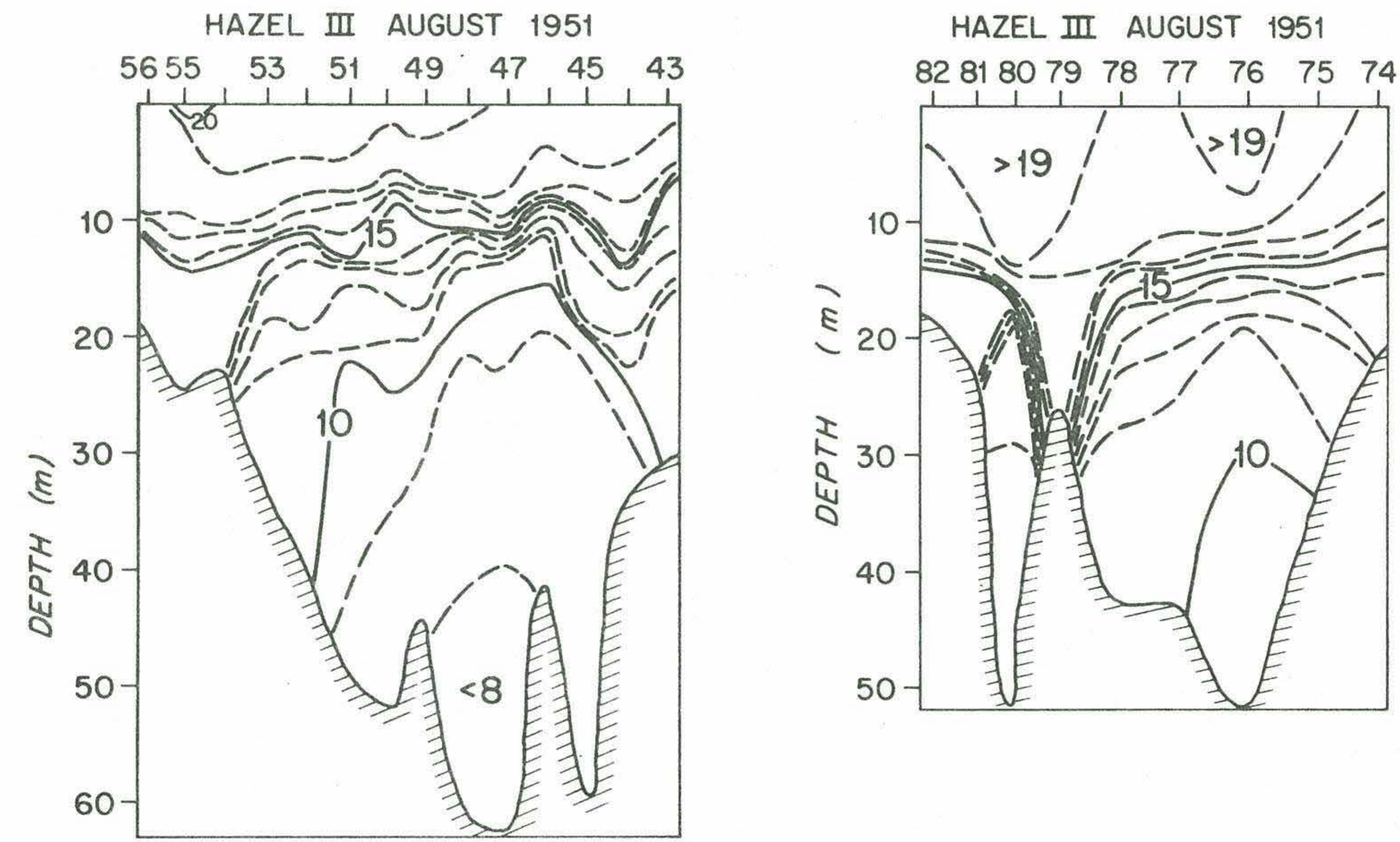


Figure 8d: Temperature profiles Hazel III August 1951, 56-43, 82-74

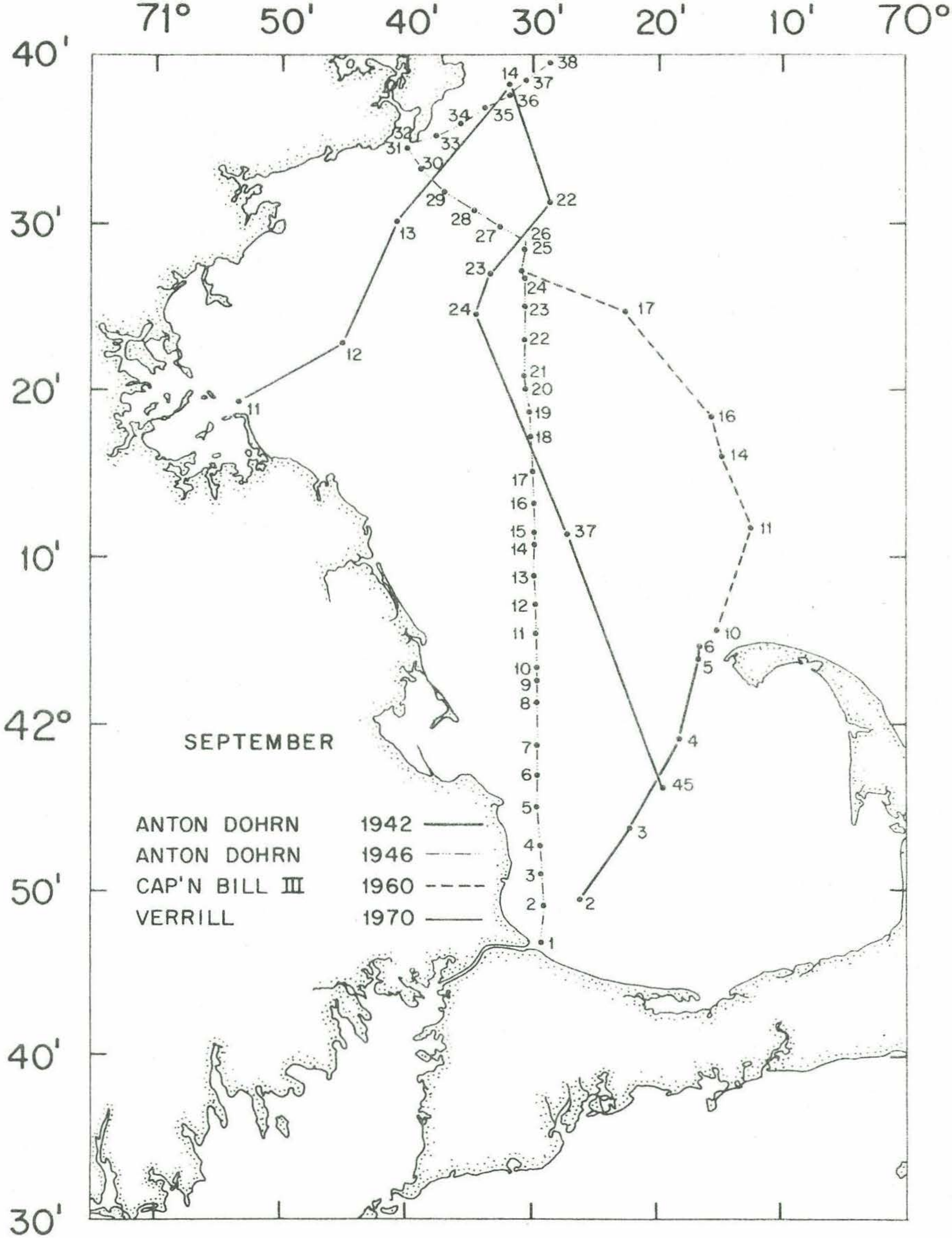


Figure 9: Location of temperature profiles for September

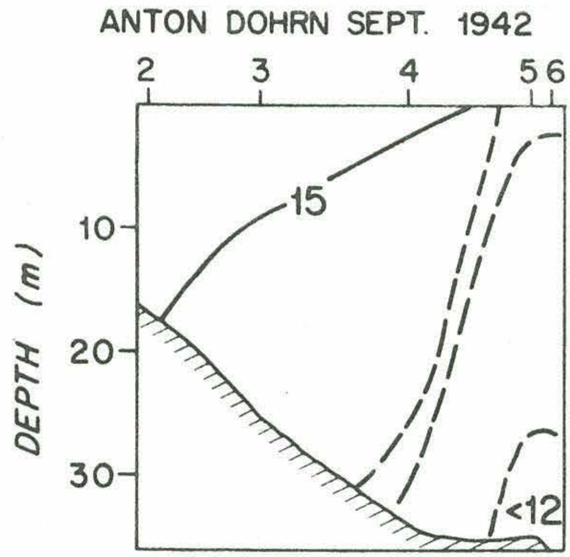


Figure 9a: Temperature profile Anton Dohrn September 1942, 2-6

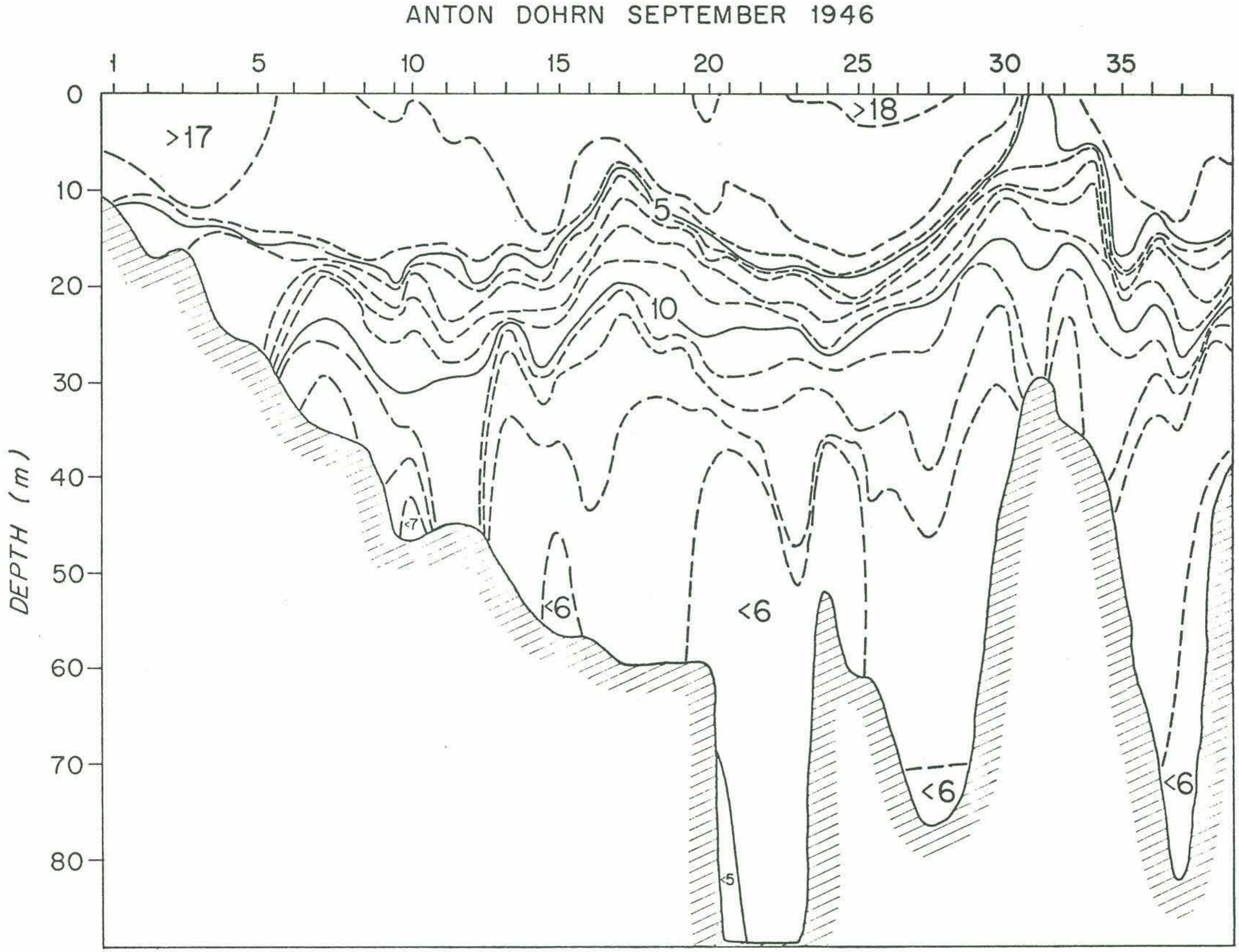


Figure 9b: Temperature profile Anton Dohrn September 1946, 1-38

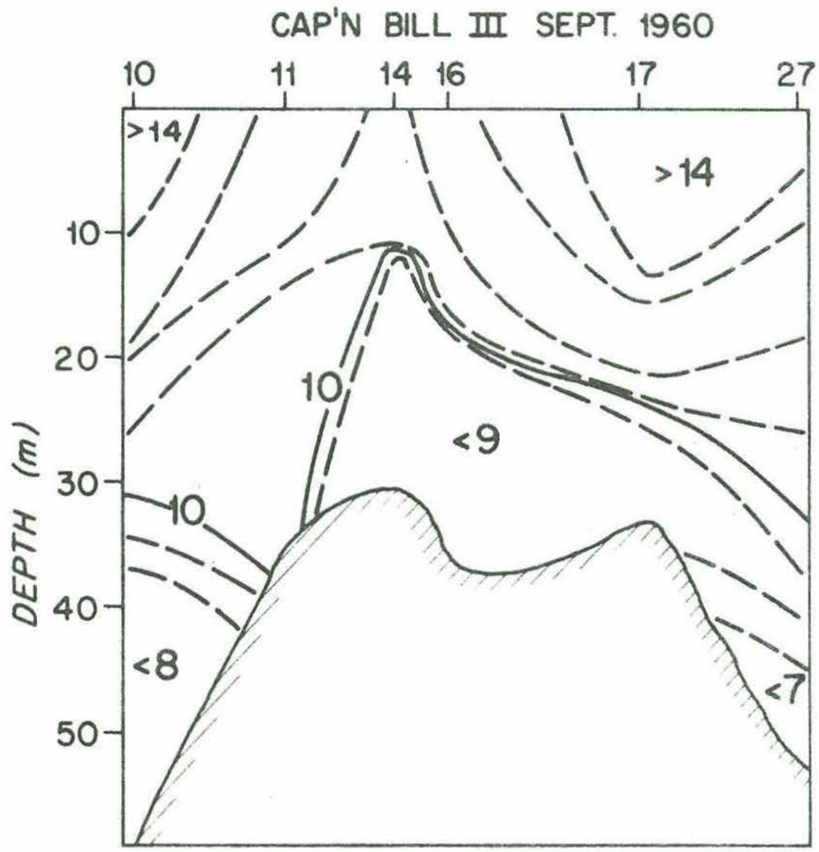


Figure 9c: Temperature profile Cap'n Bill III
September 1960, 10-27

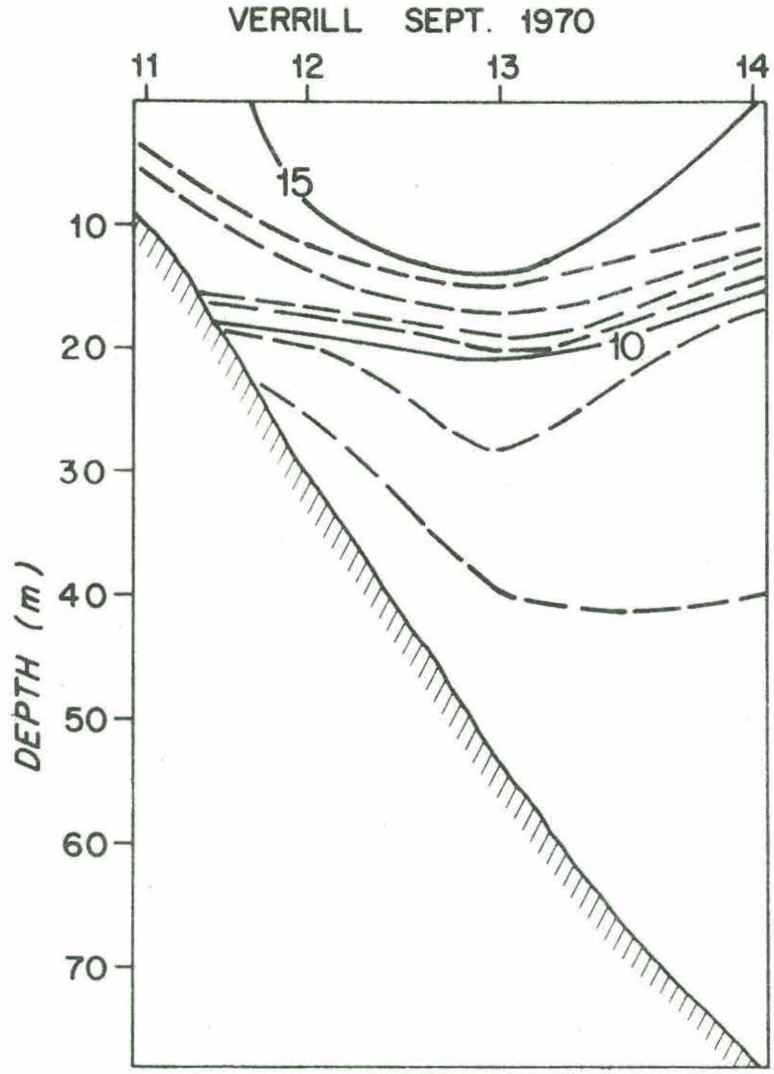


Figure 9d: Temperature profile Verrill September 1970, 11-14

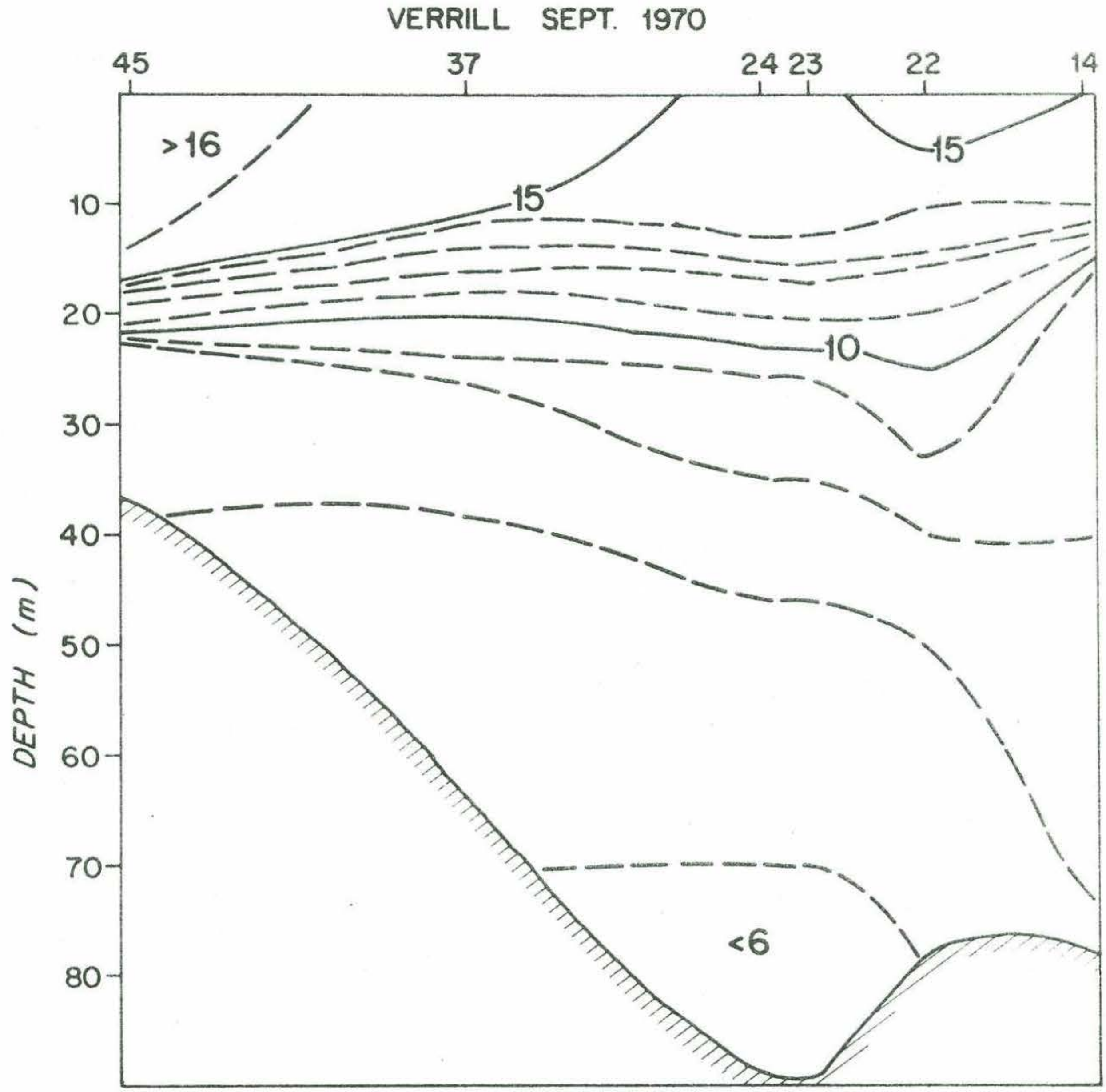


Figure 9e: Temperature profile Verrill September 1970, 45-14

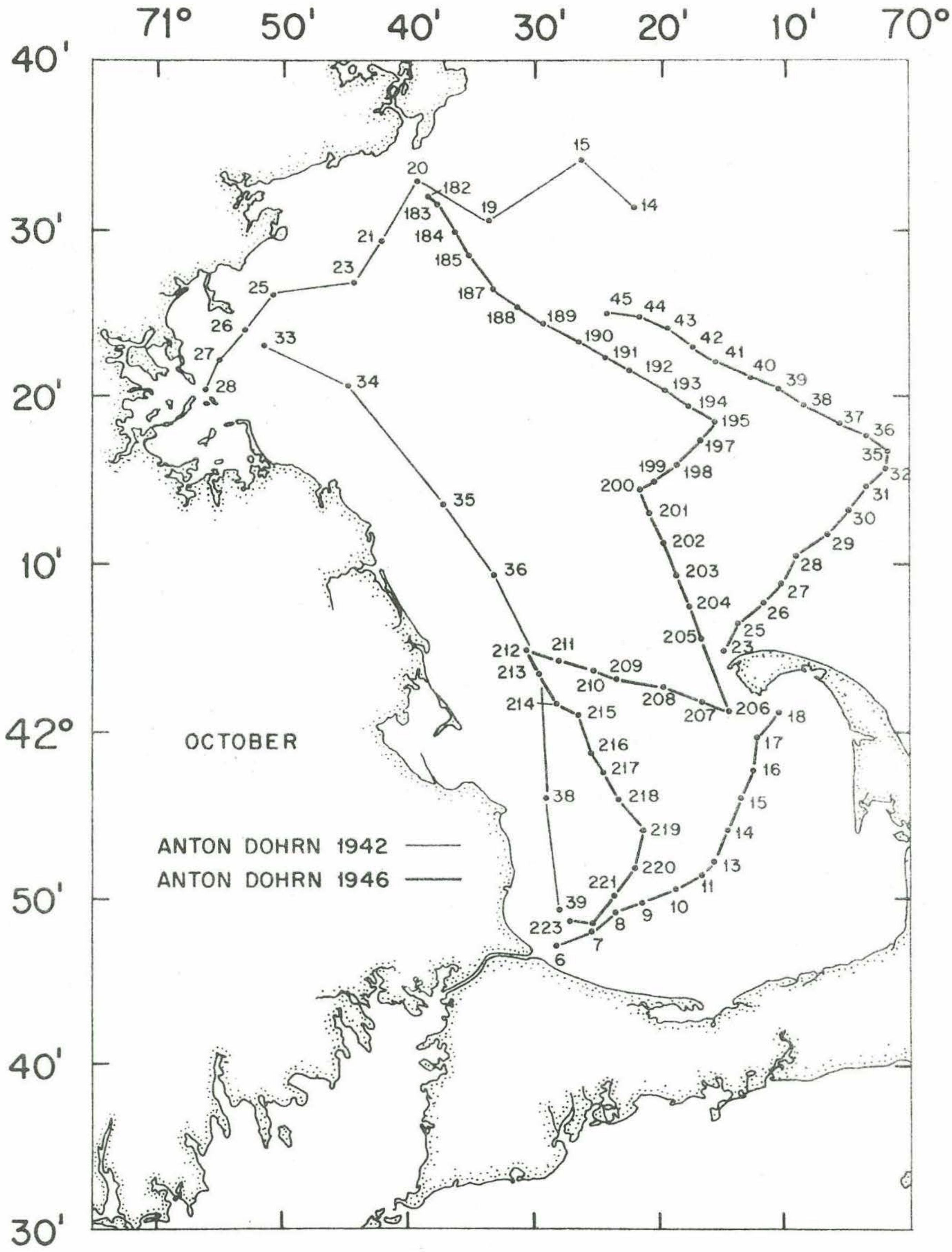


Figure 10: Location of temperature profiles for October

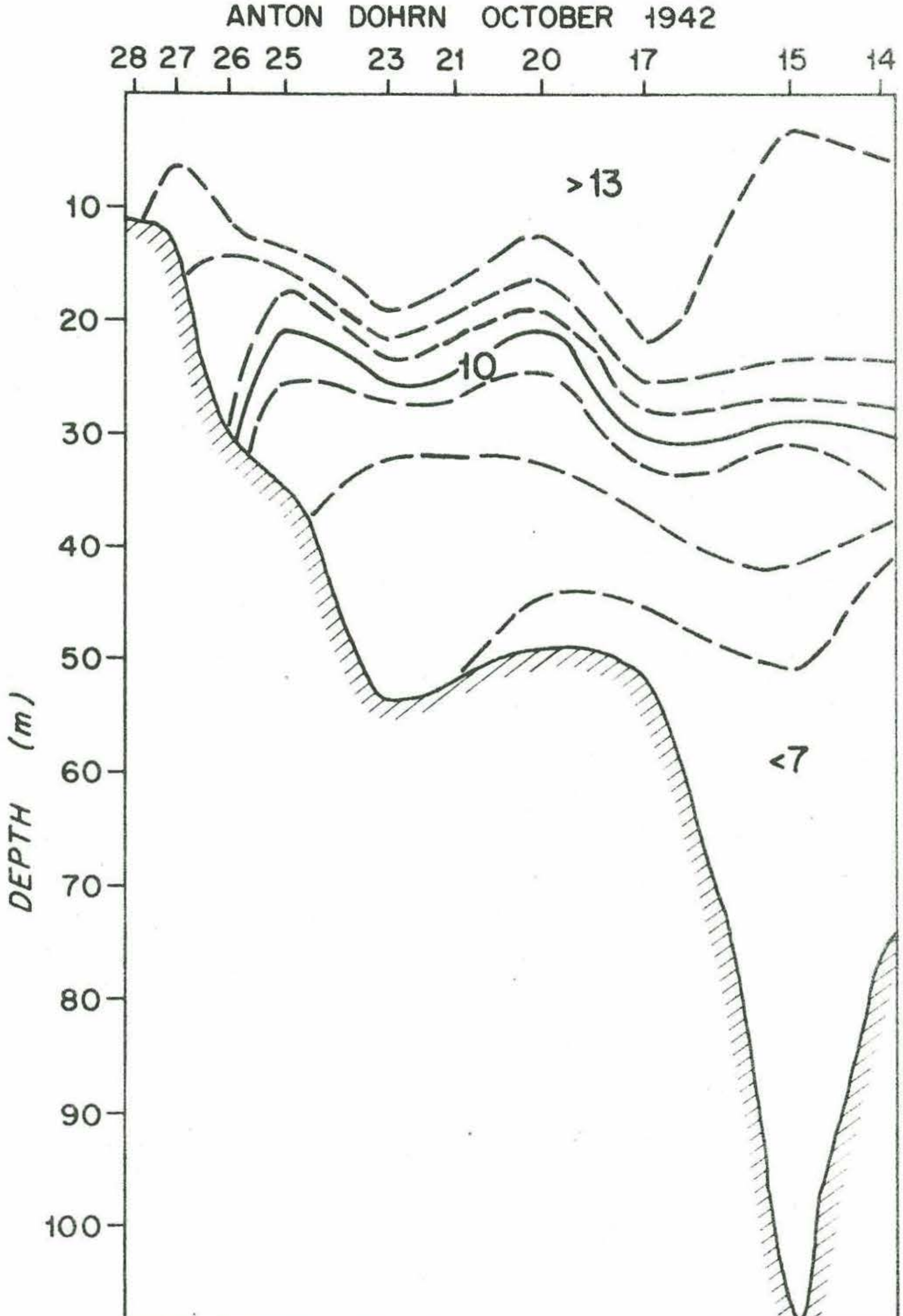


Figure 10a: Temperature profile Anton Dohrn October 1942, 28-14

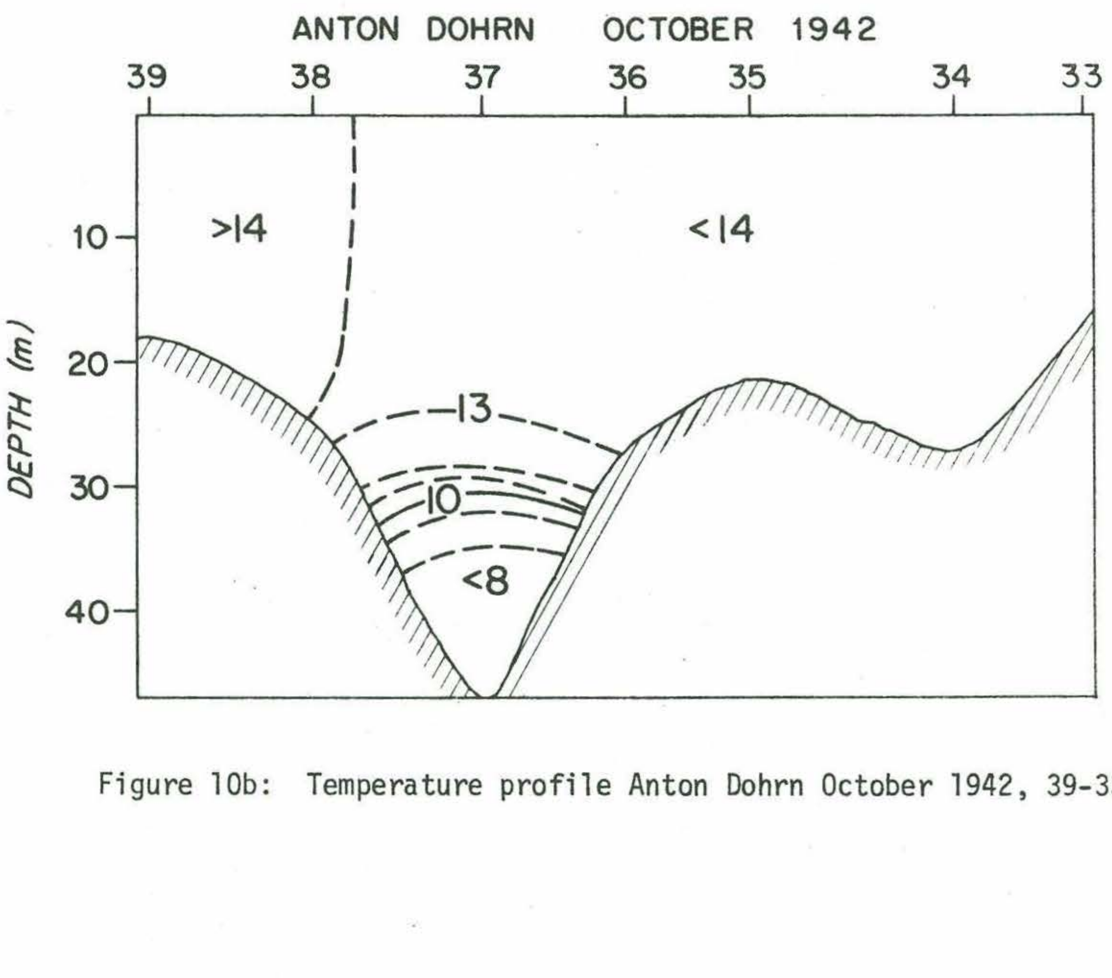


Figure 10b: Temperature profile Anton Dohrn October 1942, 39-33

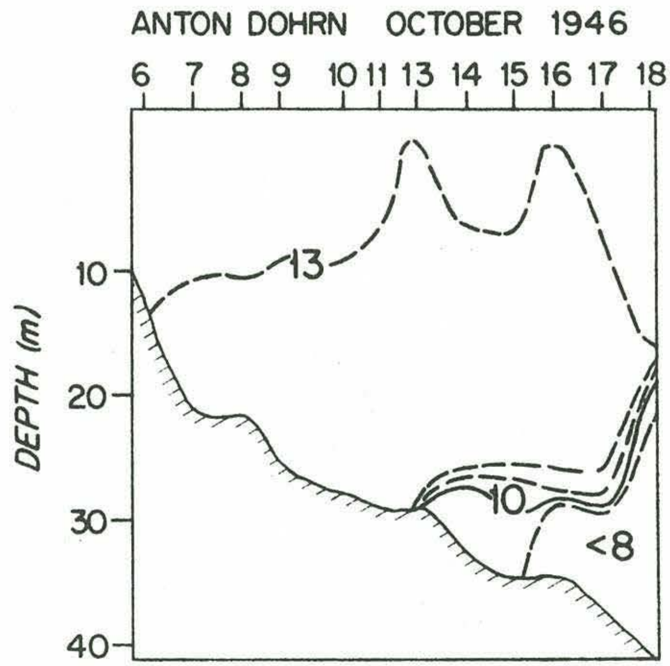


Figure 10c: Temperature profile Anton Dohrn October 1946, 6-18

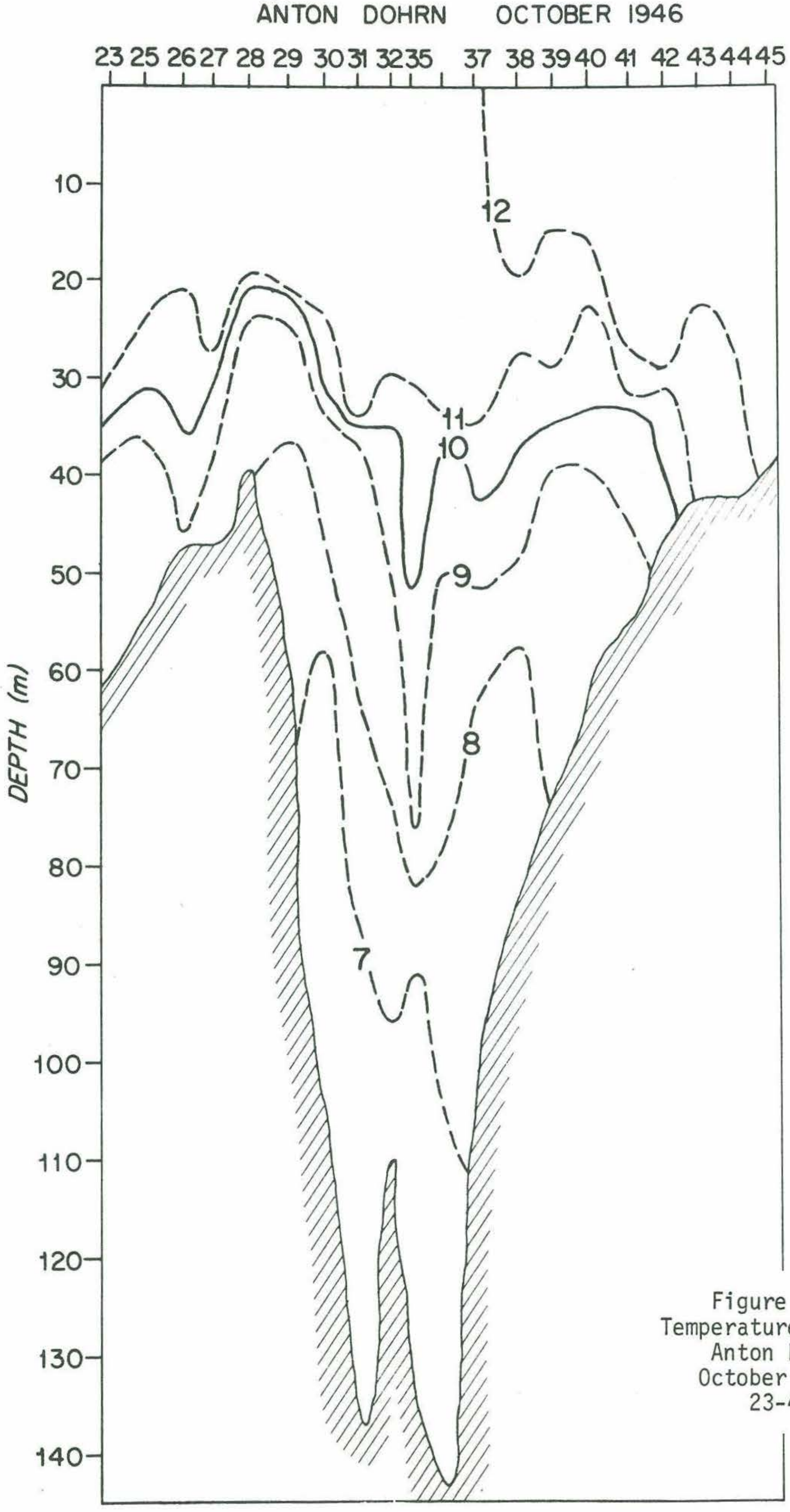


Figure 10d:
Temperature profile
Anton Dohrn
October 1946
23-45

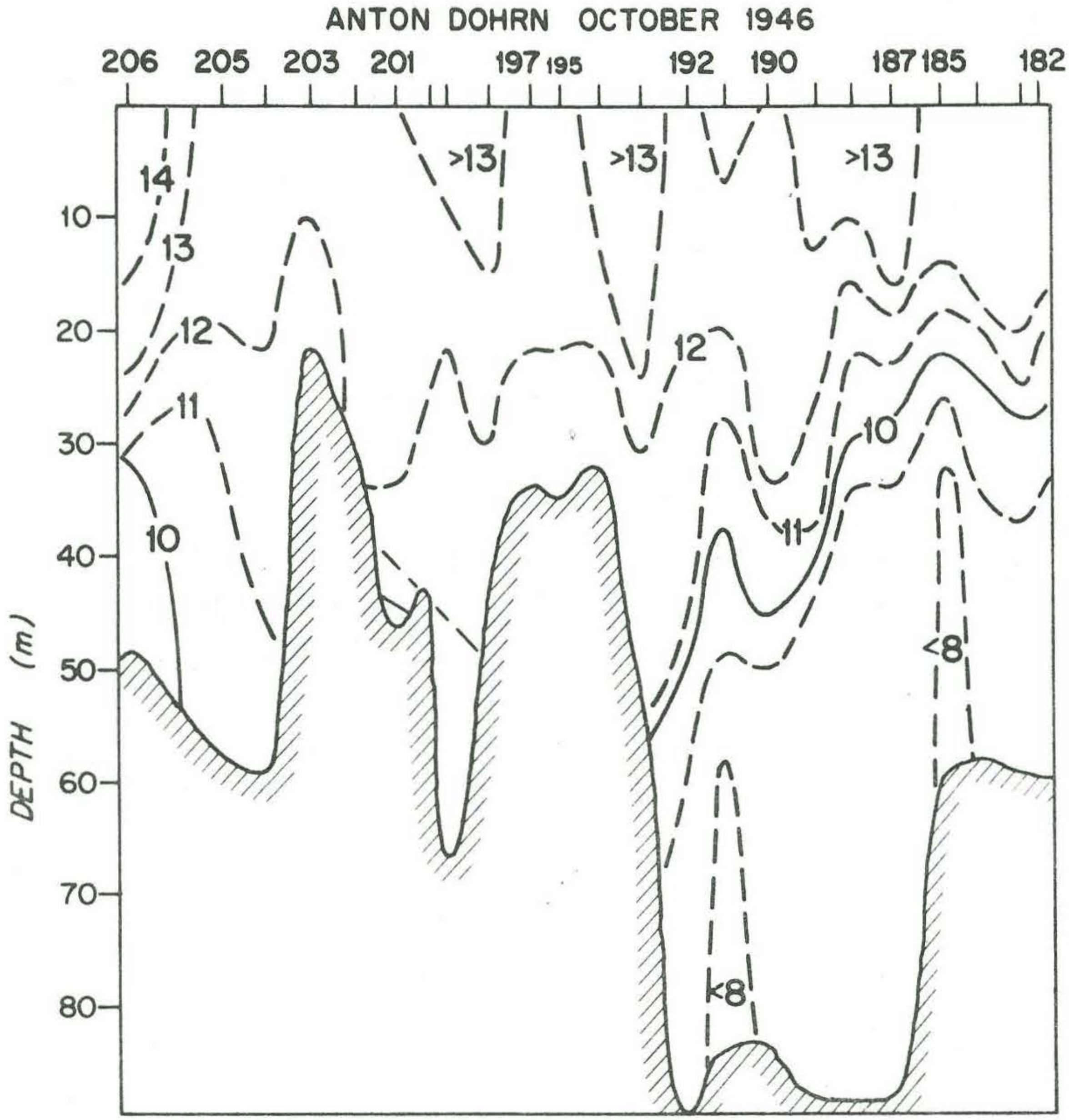


Figure 10e: Temperature profile Anton Dohrn October 1946, 206-182

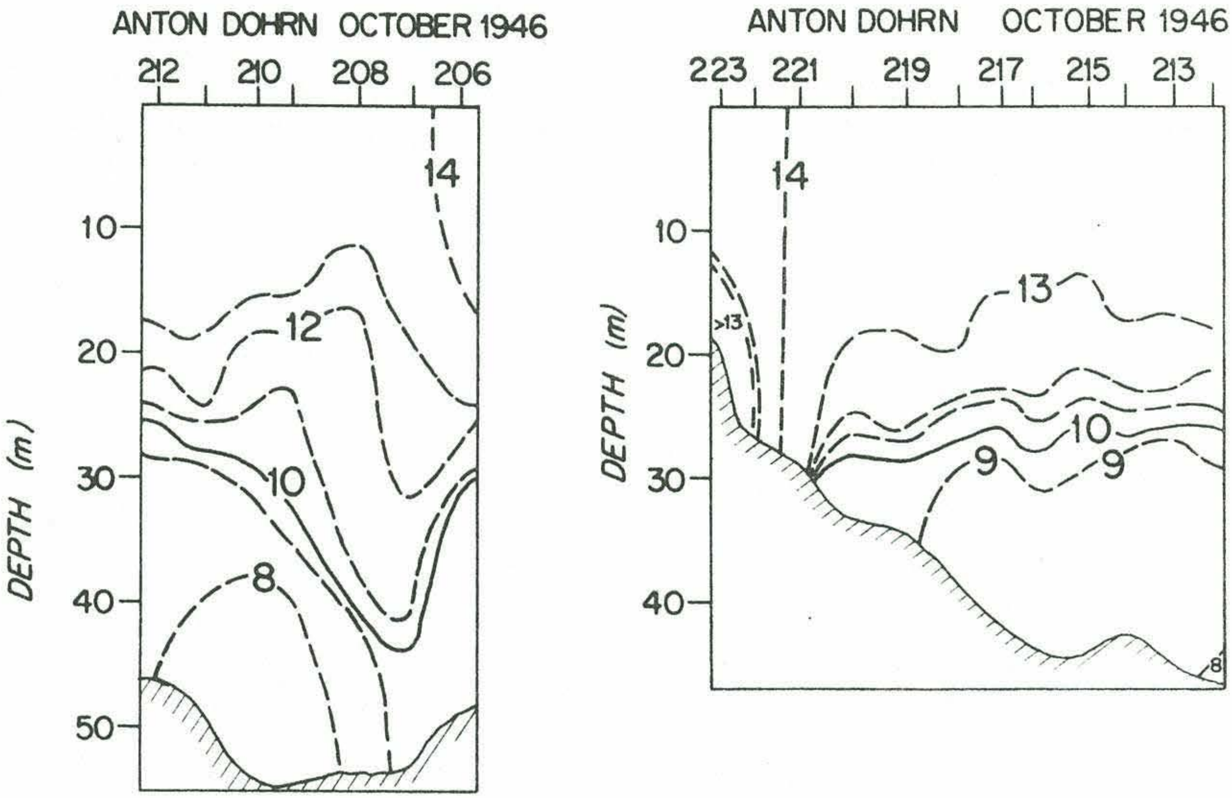


Figure 10f: Temperature profiles Anton Dohrn October 1946, 212-206, 223-212

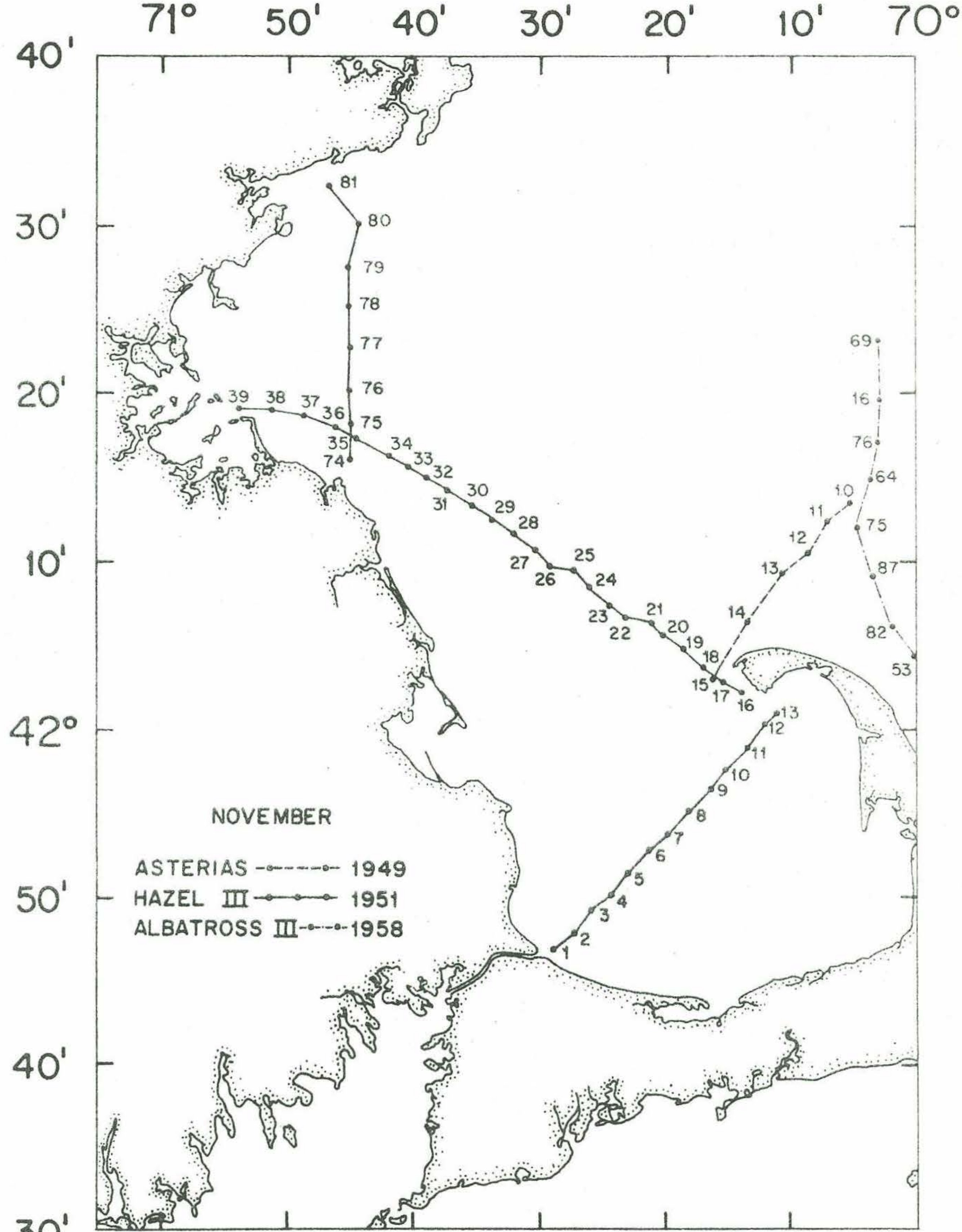


Figure 11: Location of temperature profiles for November

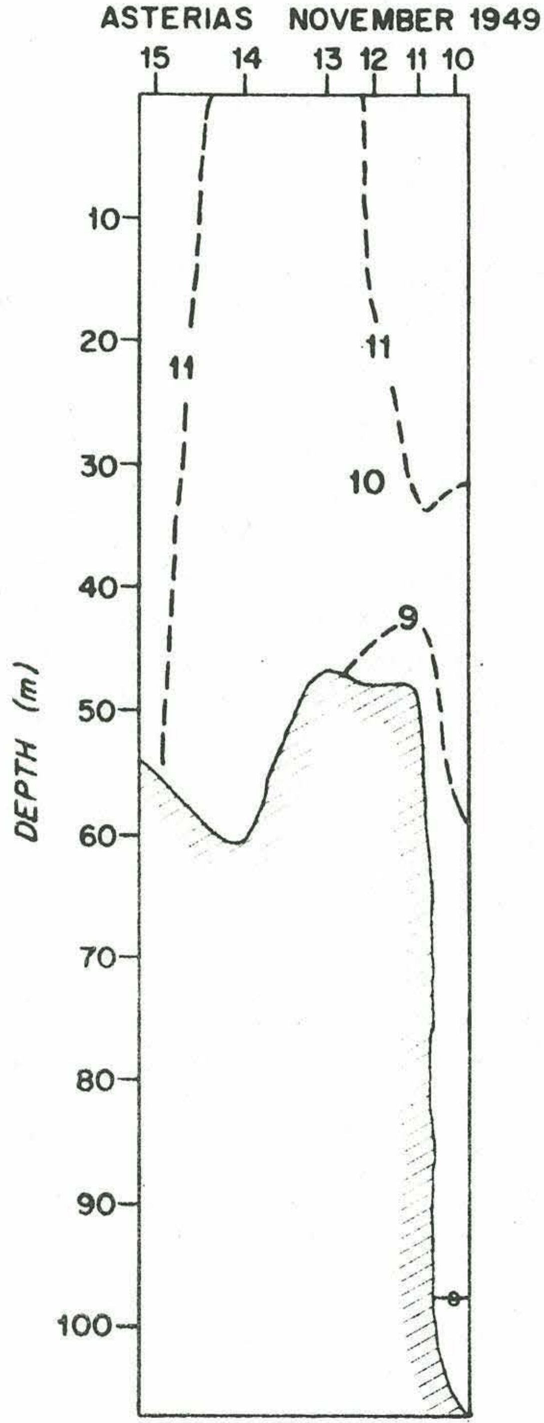


Figure 11a: Temperature profile Asterias November 1949, 15-10

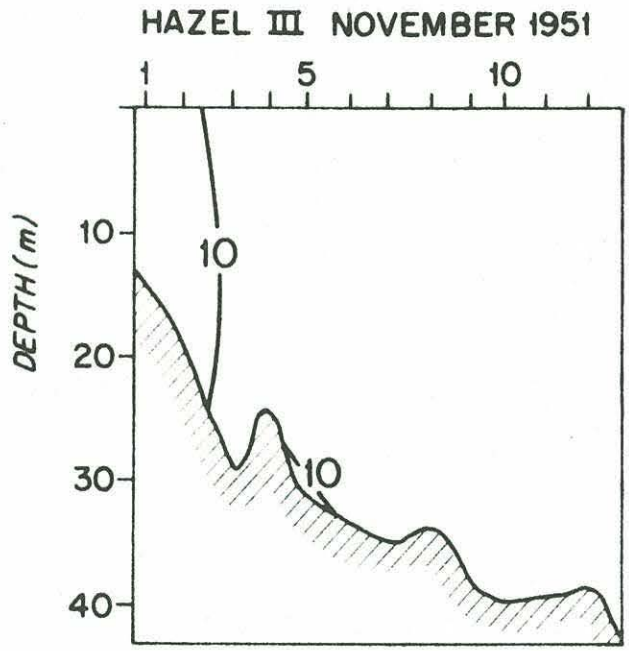


Figure 11b: Temperature profile Hazel III November 1951, 1-12

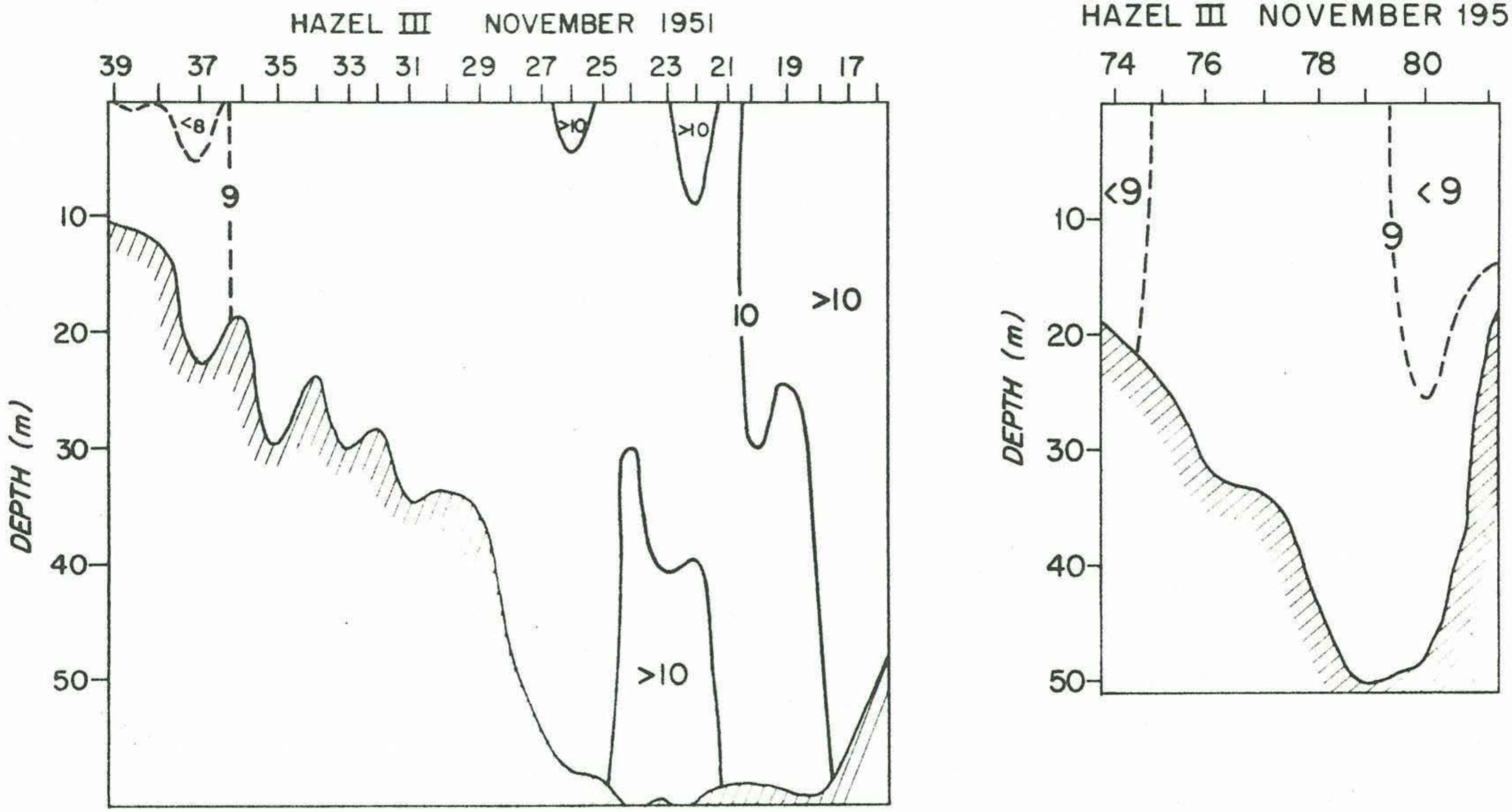


Figure 11c: Temperature profiles Hazel III November 1951, 39-16, 74-81

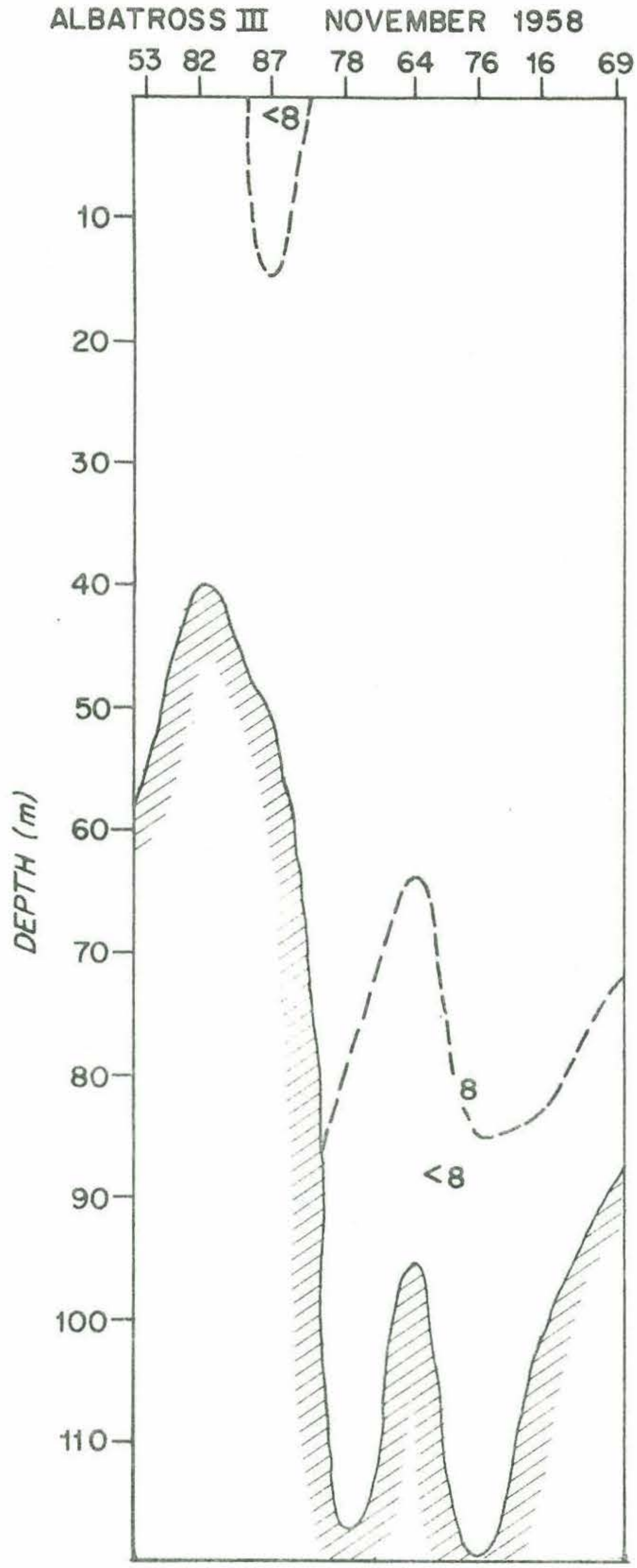


Figure 11d: Temperature profile Albatross III
November 1958, 53-69

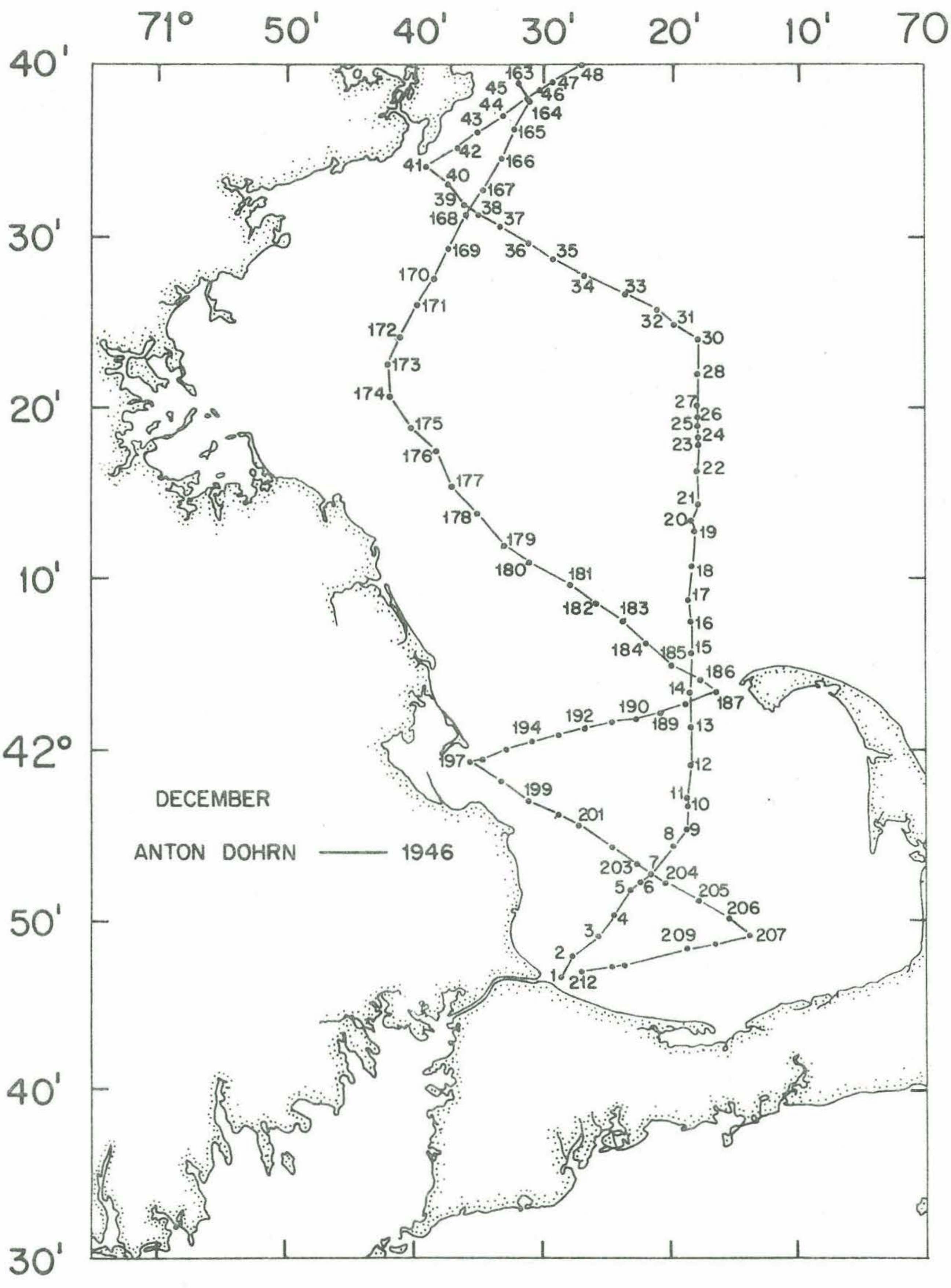


Figure 12: Location of temperature profiles for December

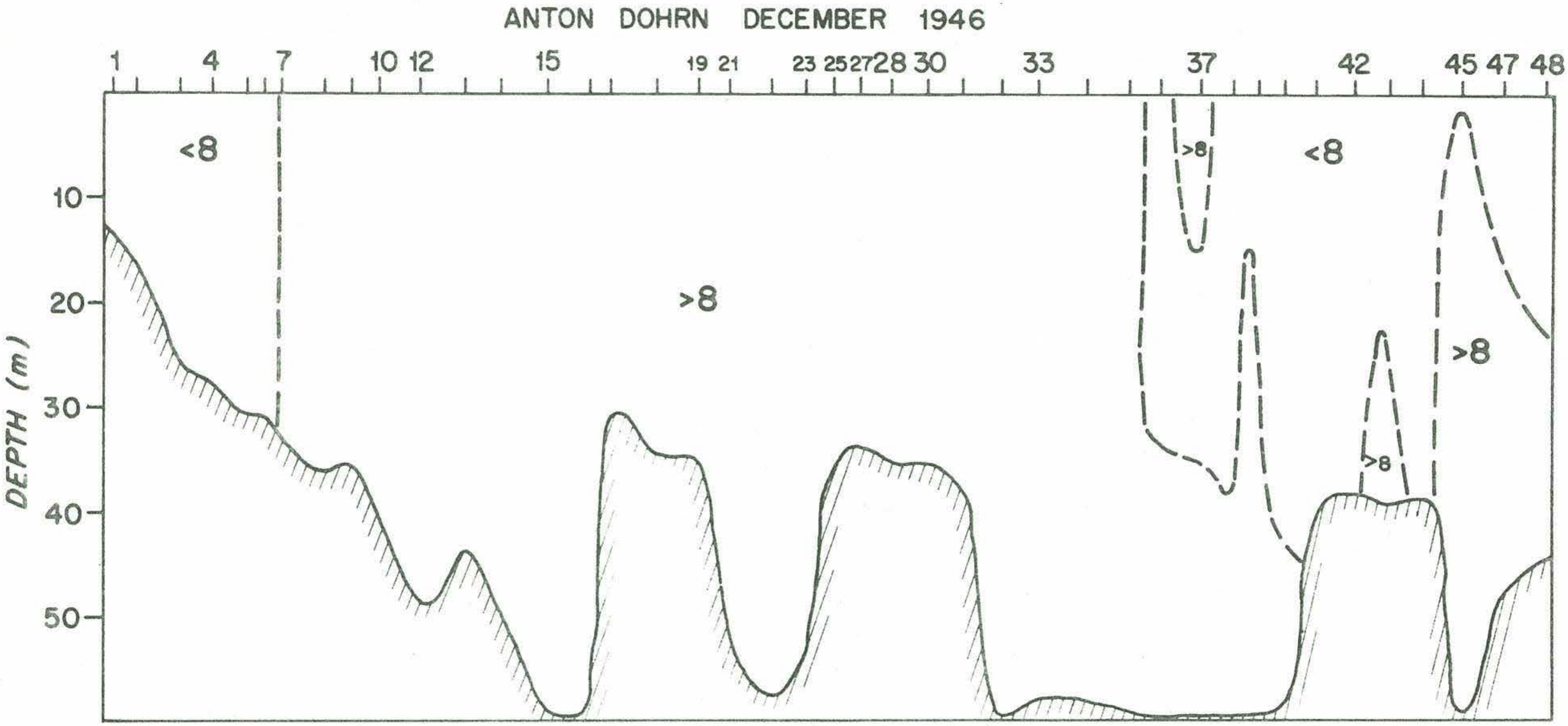


Figure 12a: Temperature profile Anton Dohrn December 1946, 1-48

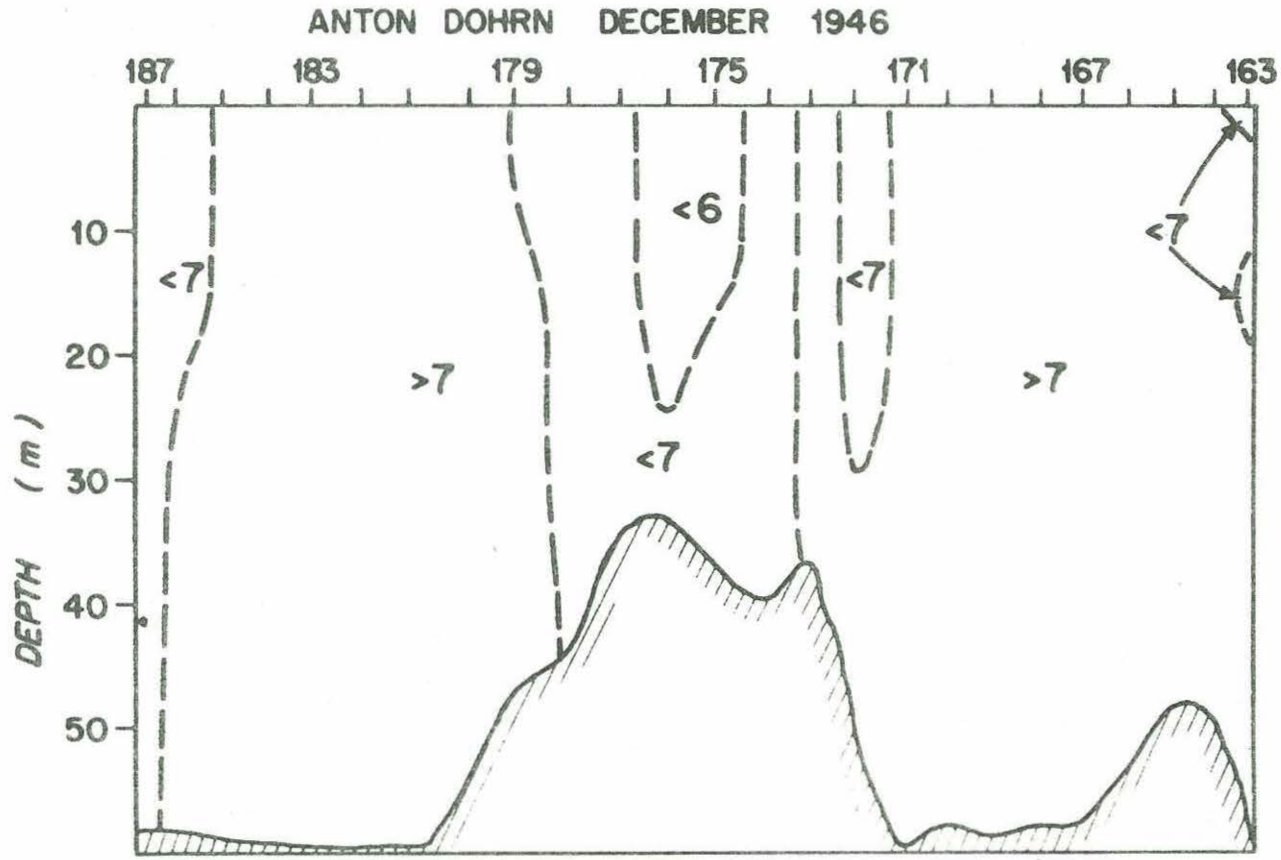


Figure 12b: Temperature profile Anton Dohrn December 1946, 187-163

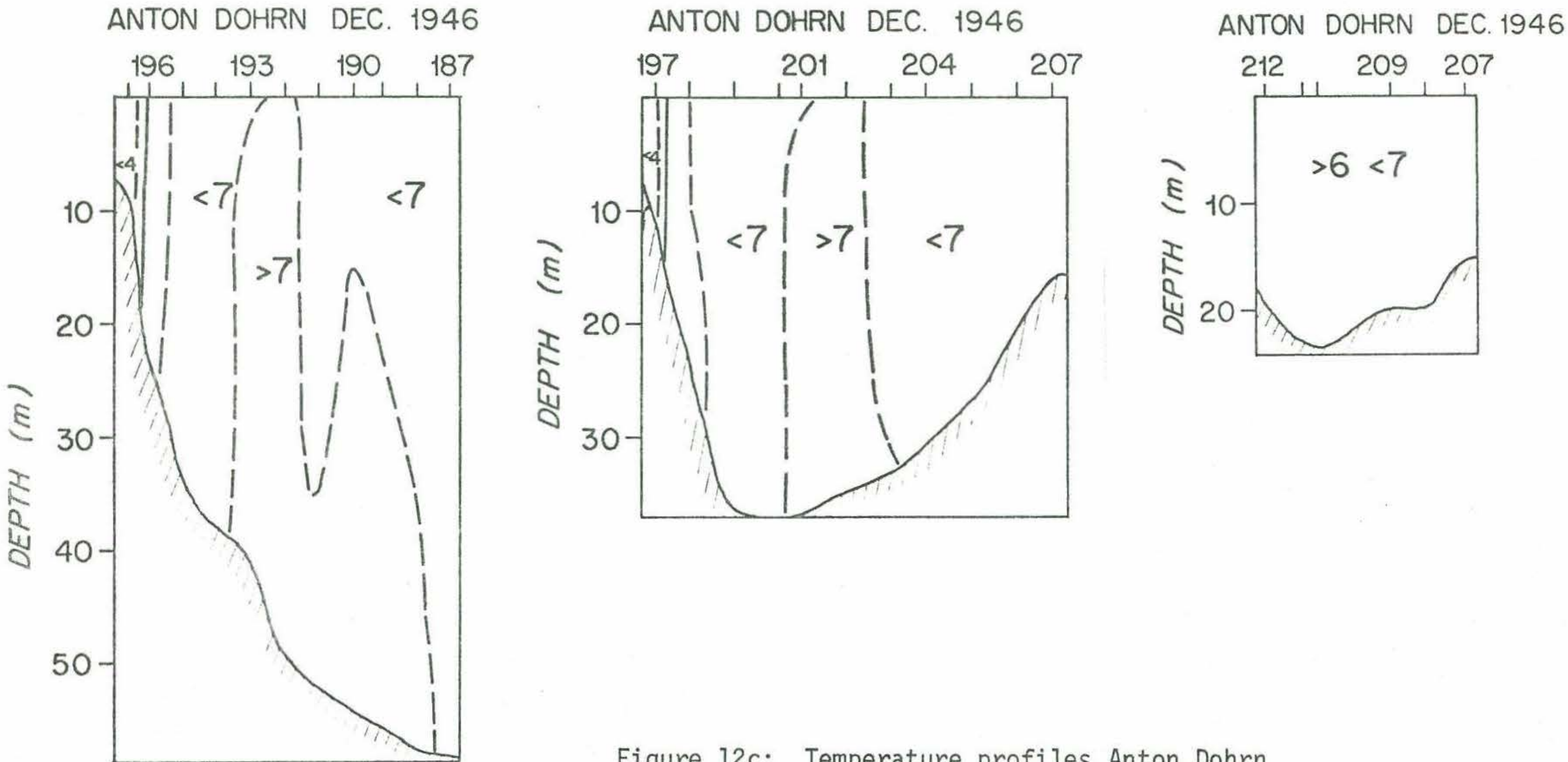


Figure 12c: Temperature profiles Anton Dohrn December 1946, 196-187, 197-207, 212-207

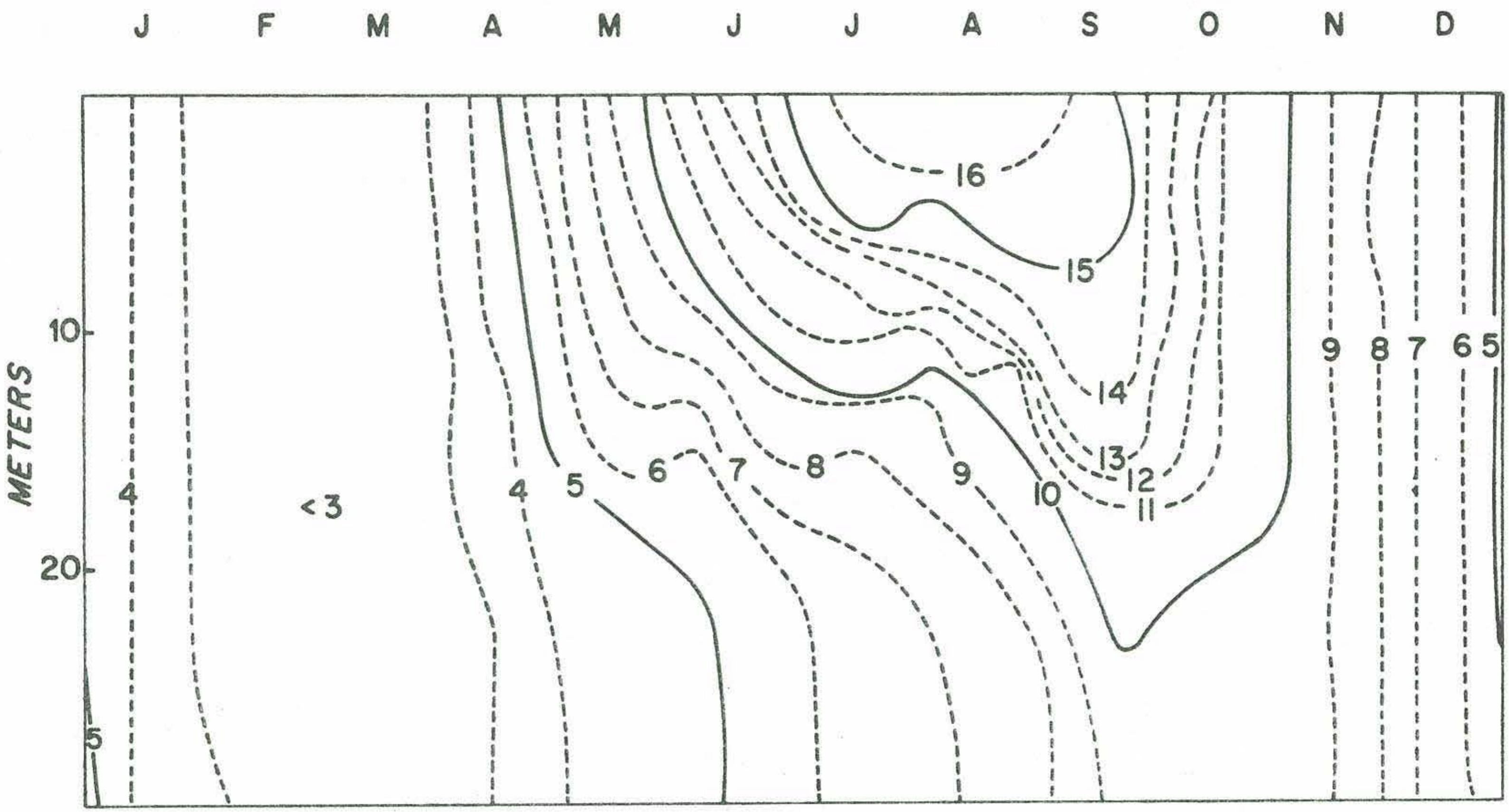


Figure 13: Profile of mean annual temperature cycle at Boston Lightship, 1956-1970

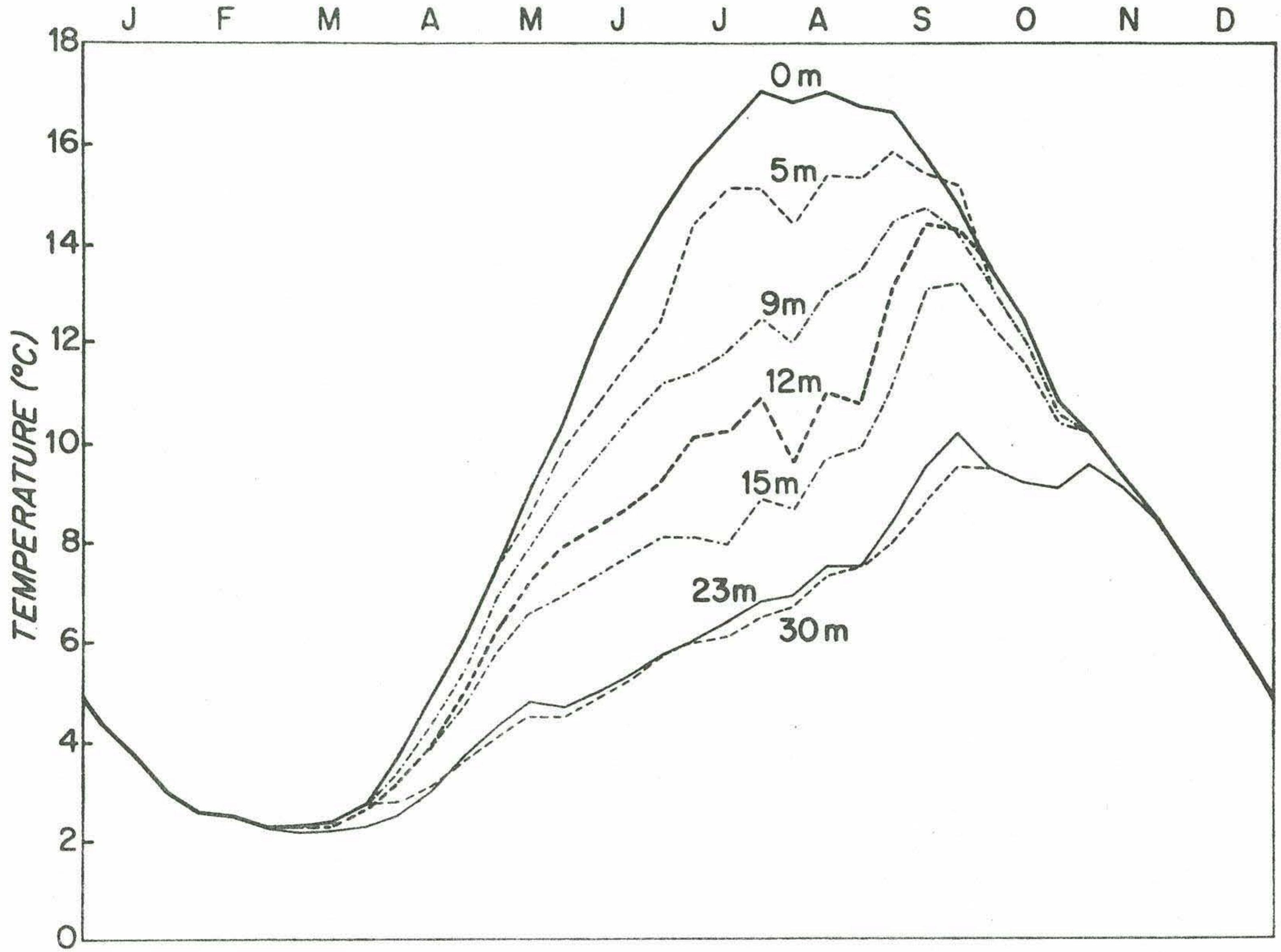


Figure 14: Annual cycle of temperature at standard levels at Boston Lightship, mean for 1956-1970

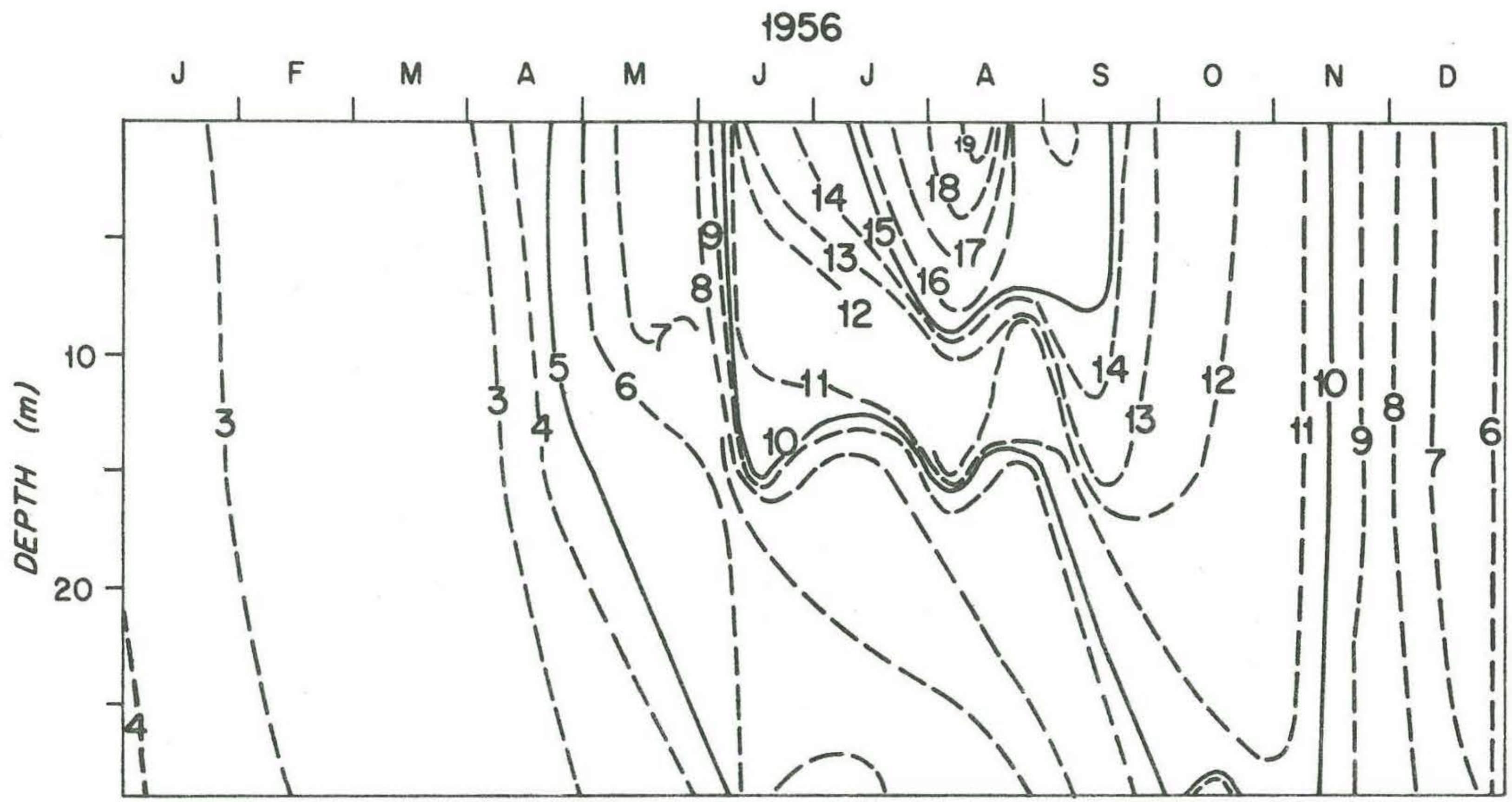


Figure 15: Profile of annual temperature cycle at Boston Lightship for 1956

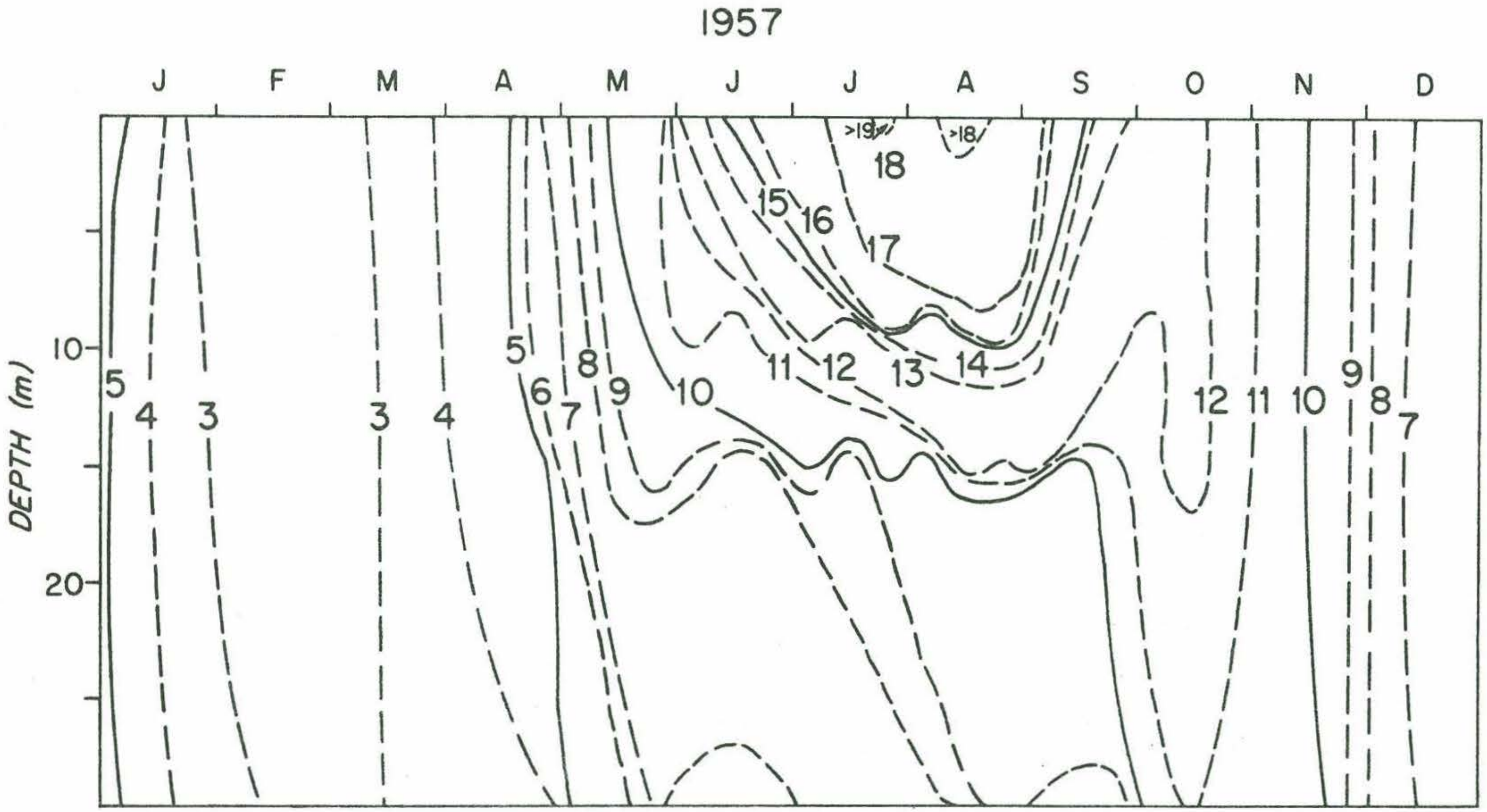


Figure 16: Profile of annual temperature cycle at Boston Lightship for 1957

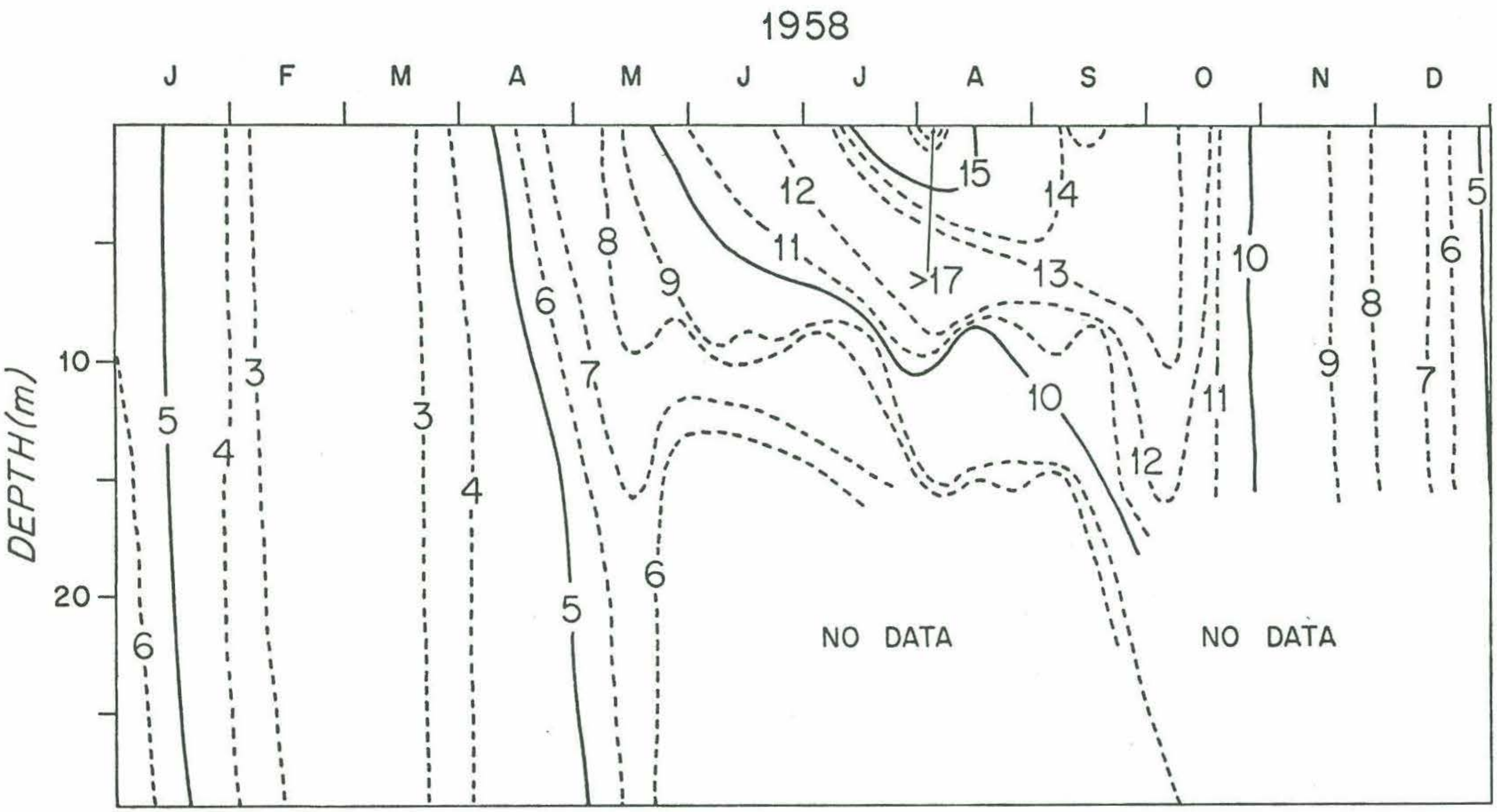


Figure 17: Profile of annual temperature cycle at Boston Lightship for 1958

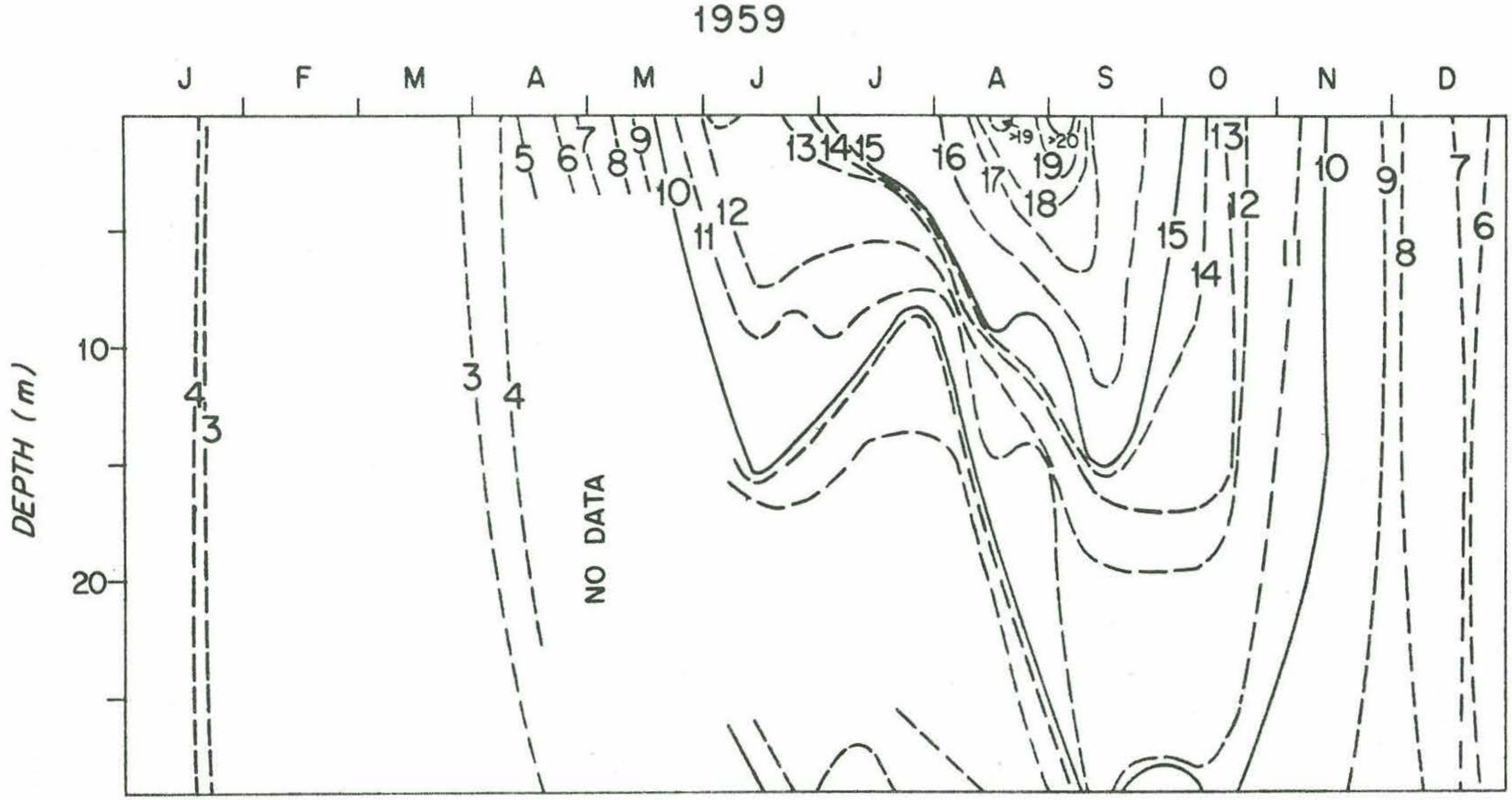


Figure 18: Profile of annual temperature cycle at Boston Lightship for 1959

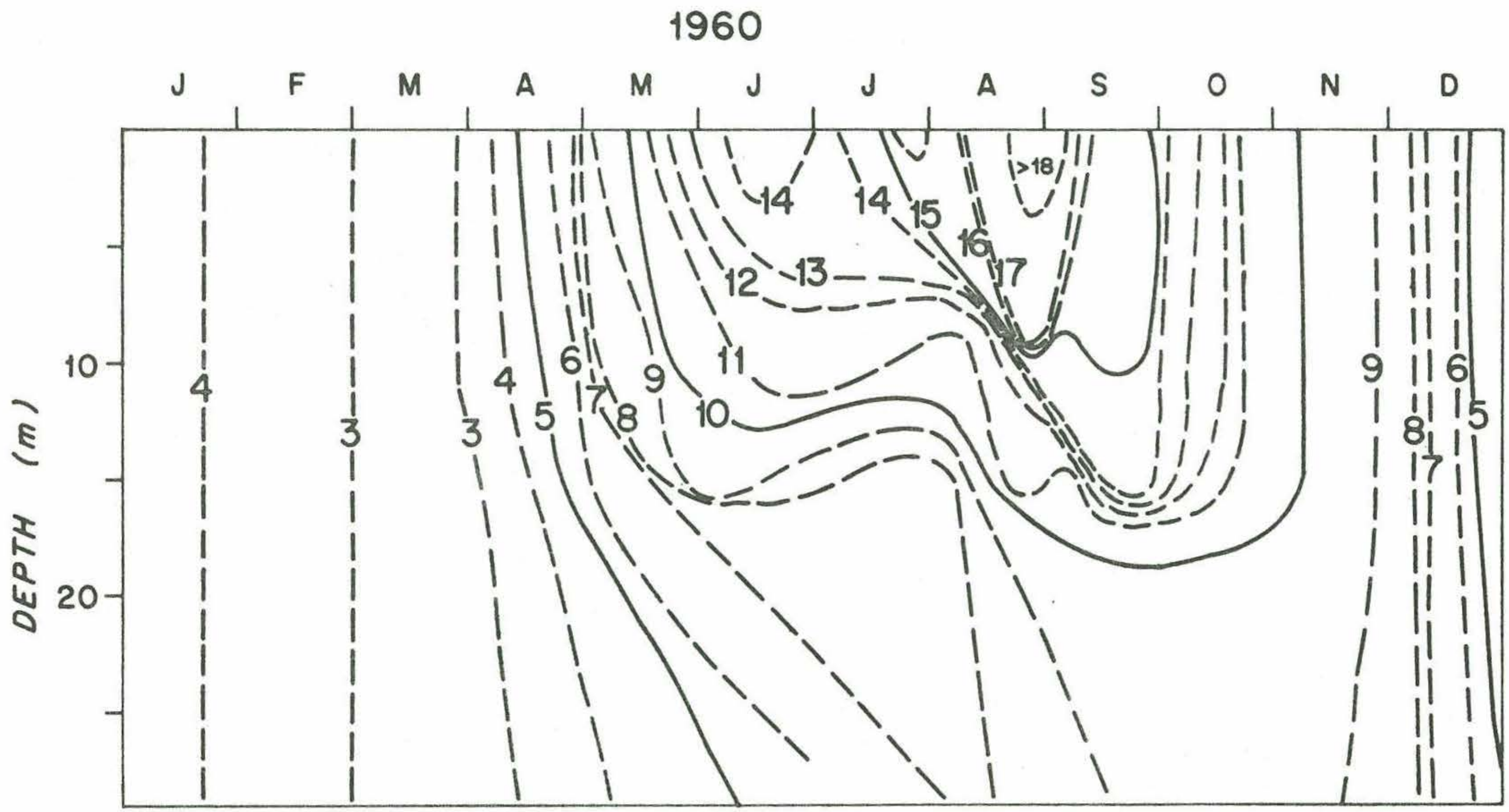


Figure 19: Profile of annual temperature cycle at Boston Lightship for 1960

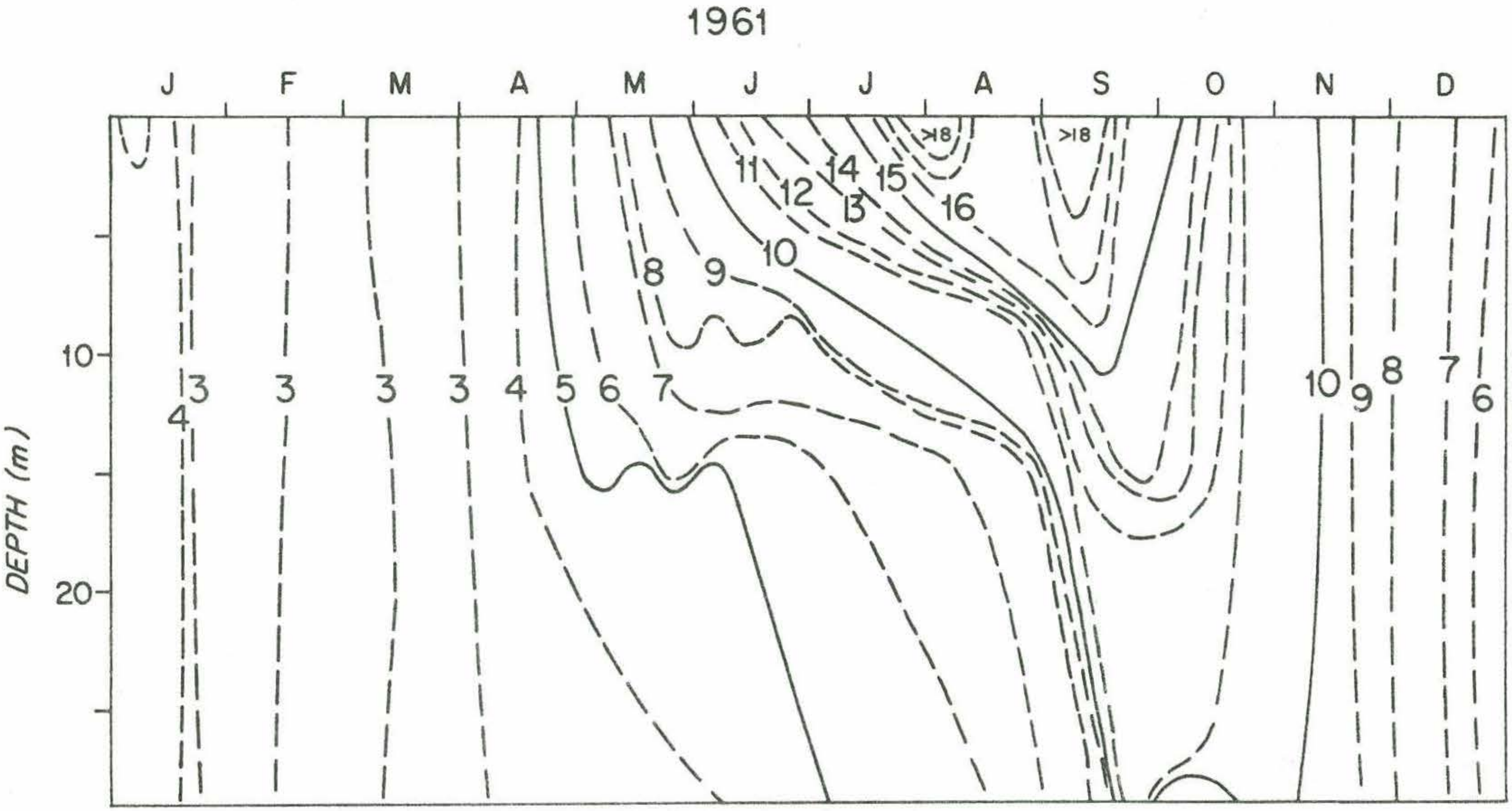


Figure 20: Profile of annual temperature cycle at Boston Lightship for 1961

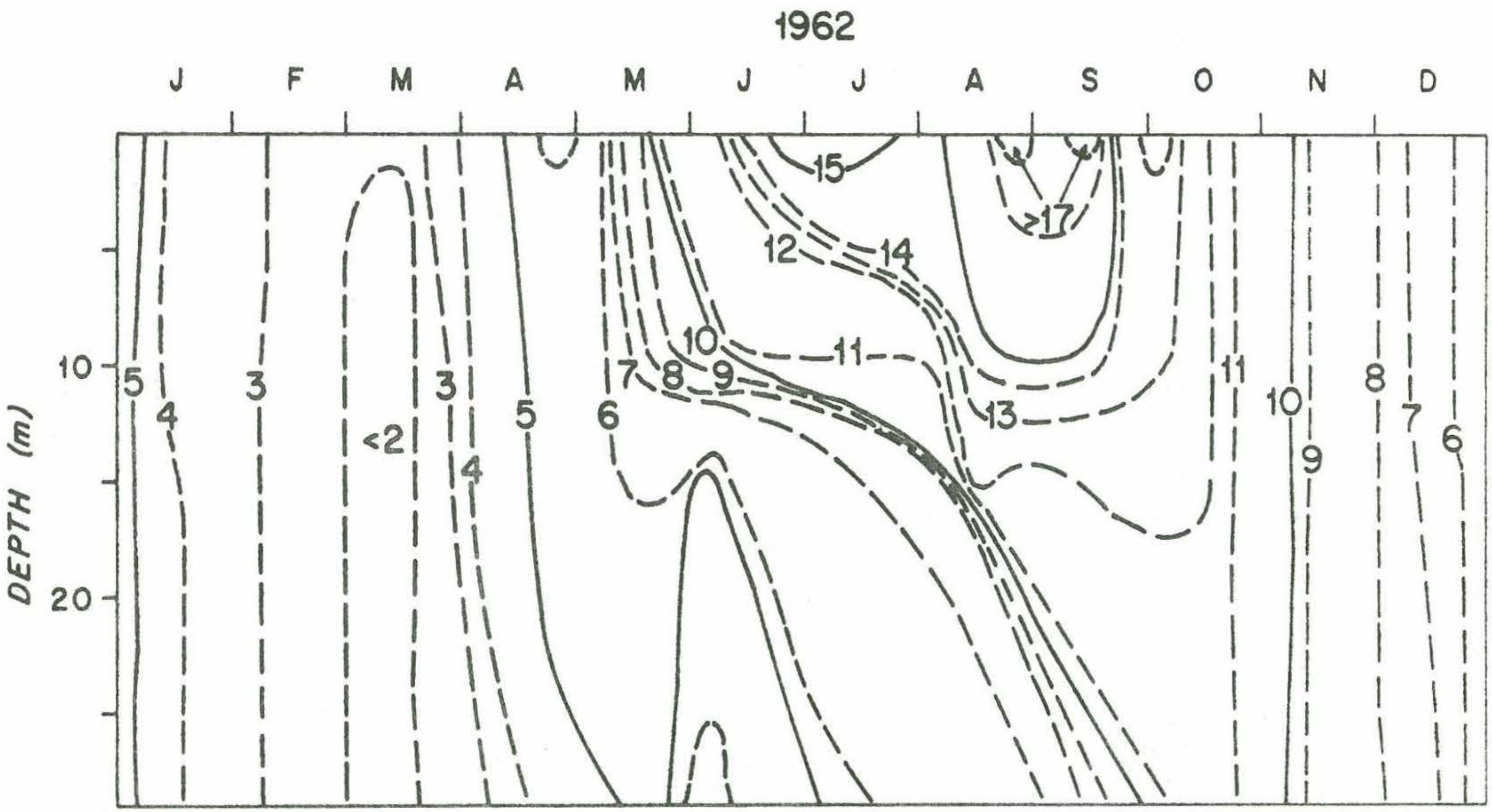


Figure 21: Profile of annual temperature cycle at Boston Lightship for 1962

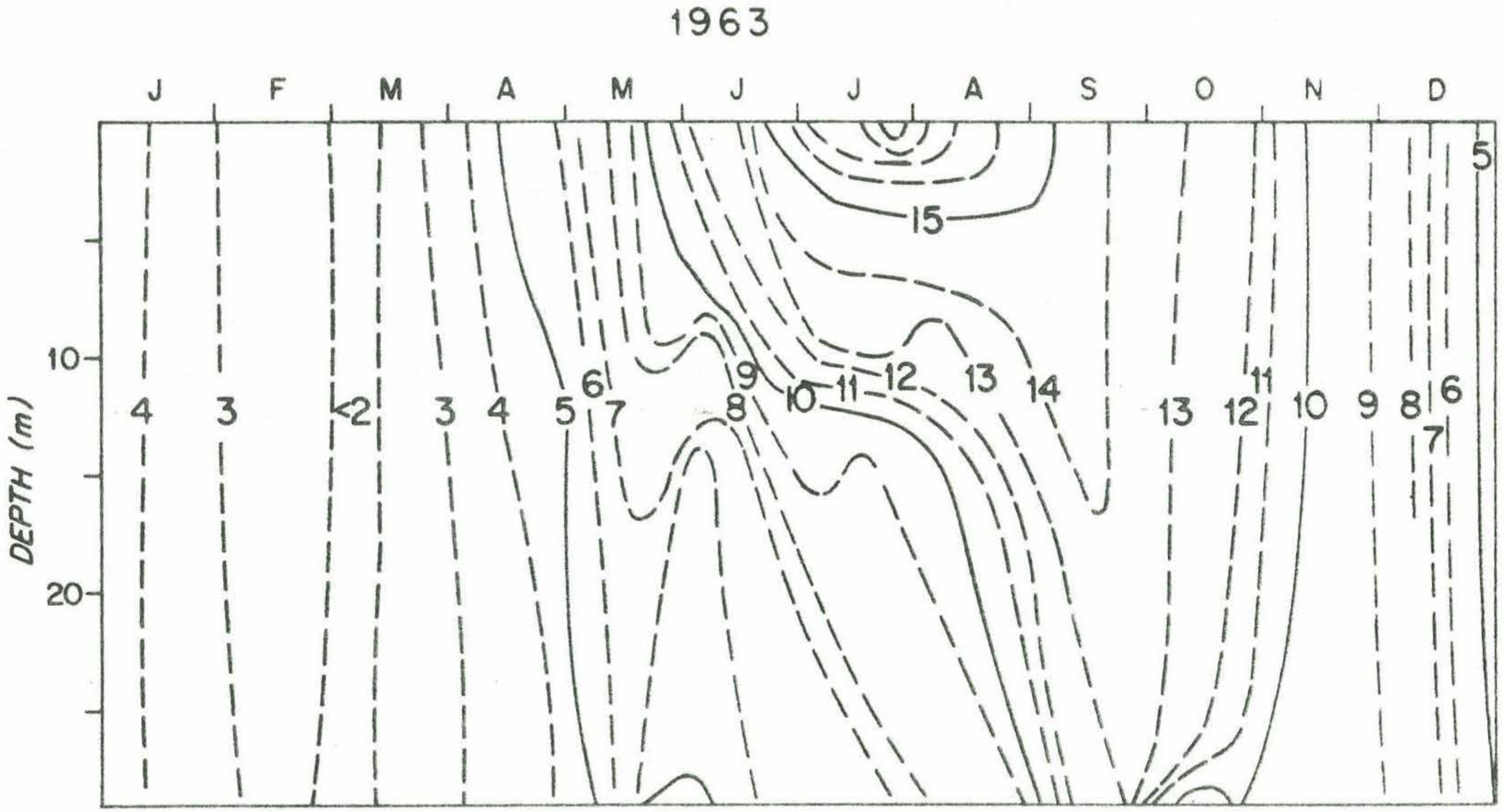


Figure 22: Profile of annual temperature cycle at Boston Lightship for 1963

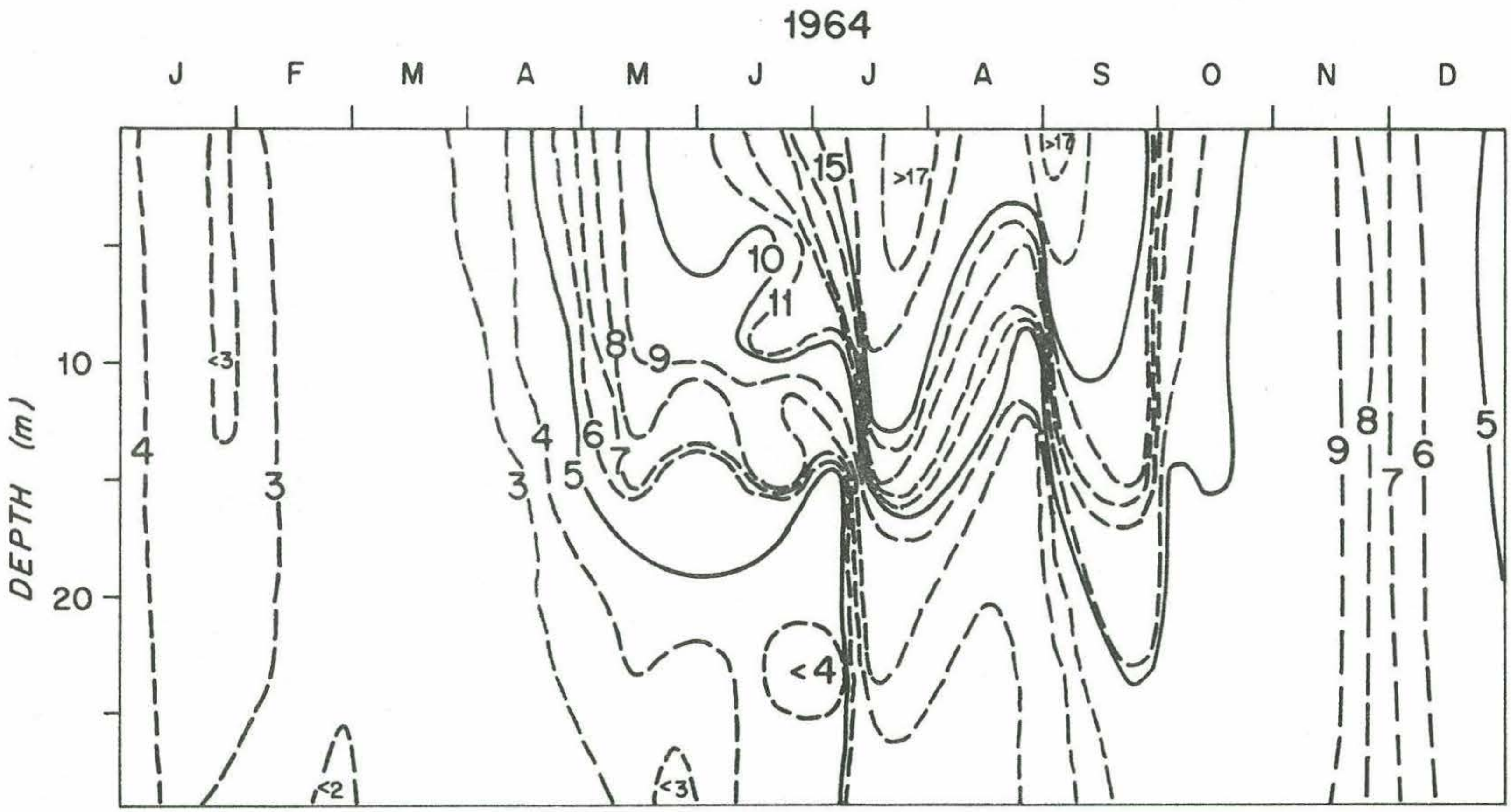


Figure 23: Profile of annual temperature cycle at Boston Lightship for 1964

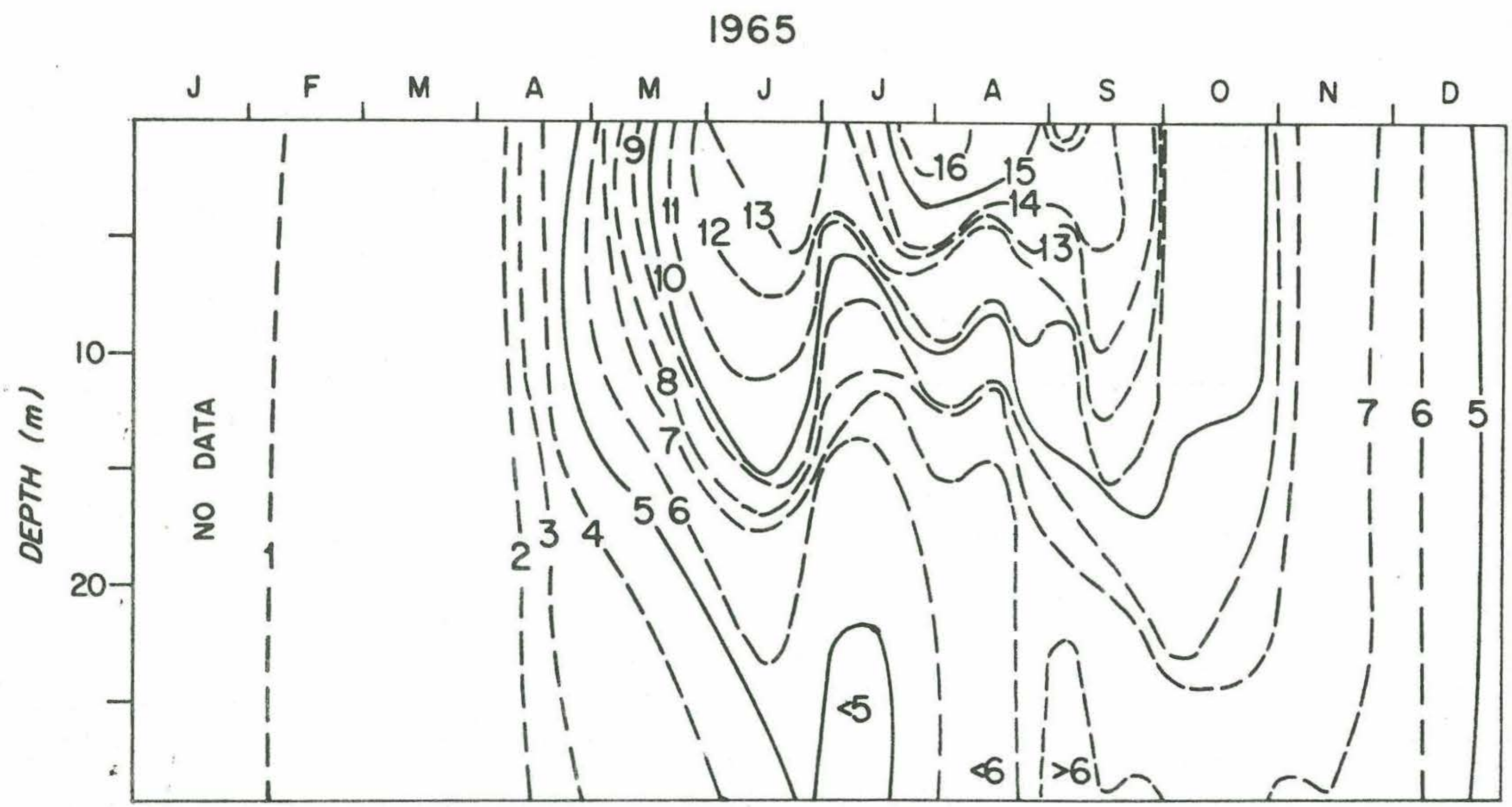


Figure 24: Profile of annual temperature cycle at Boston Lightship for 1965

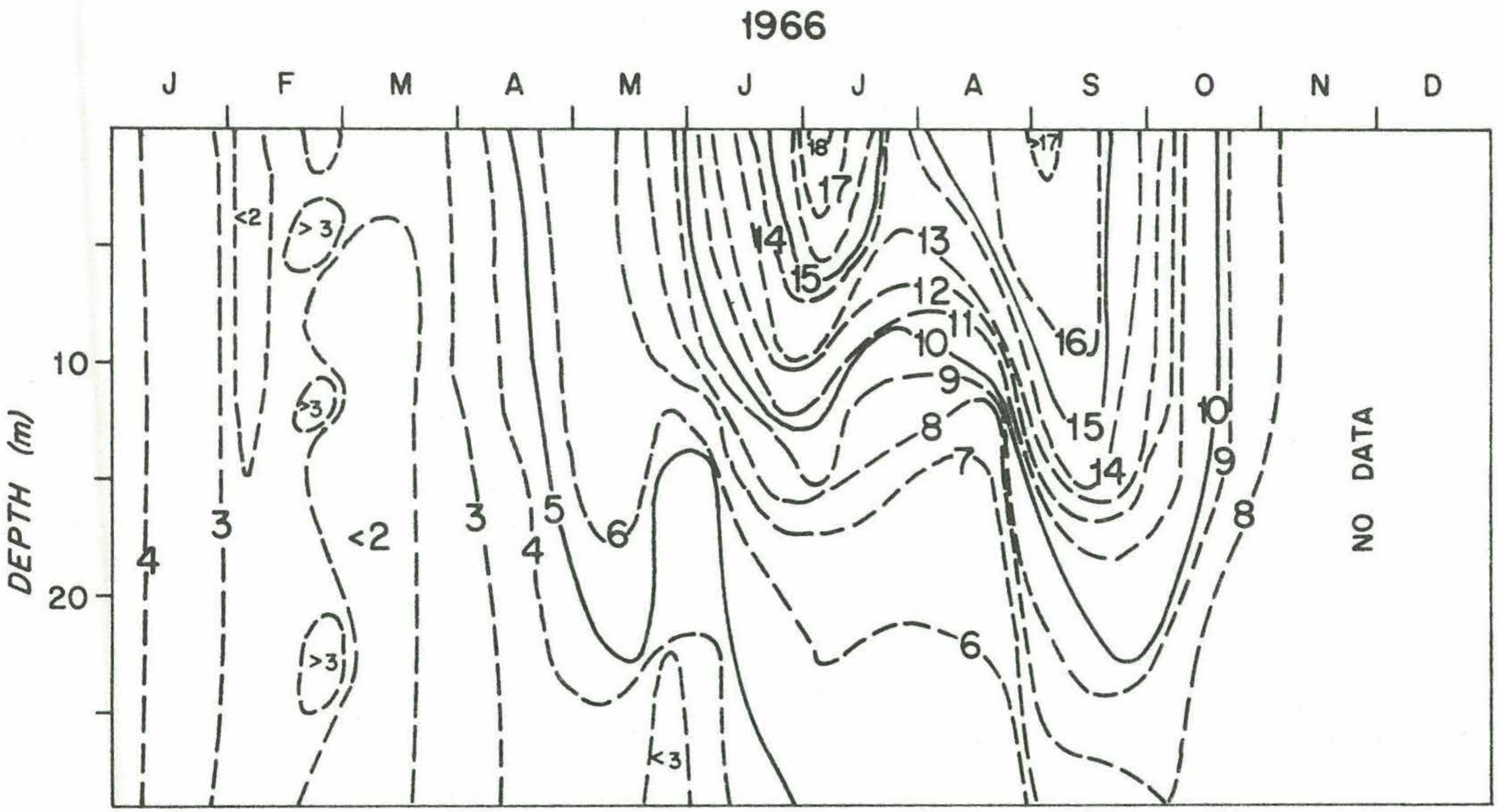


Figure 25: Profile of annual temperature cycle at Boston Lightship for 1966

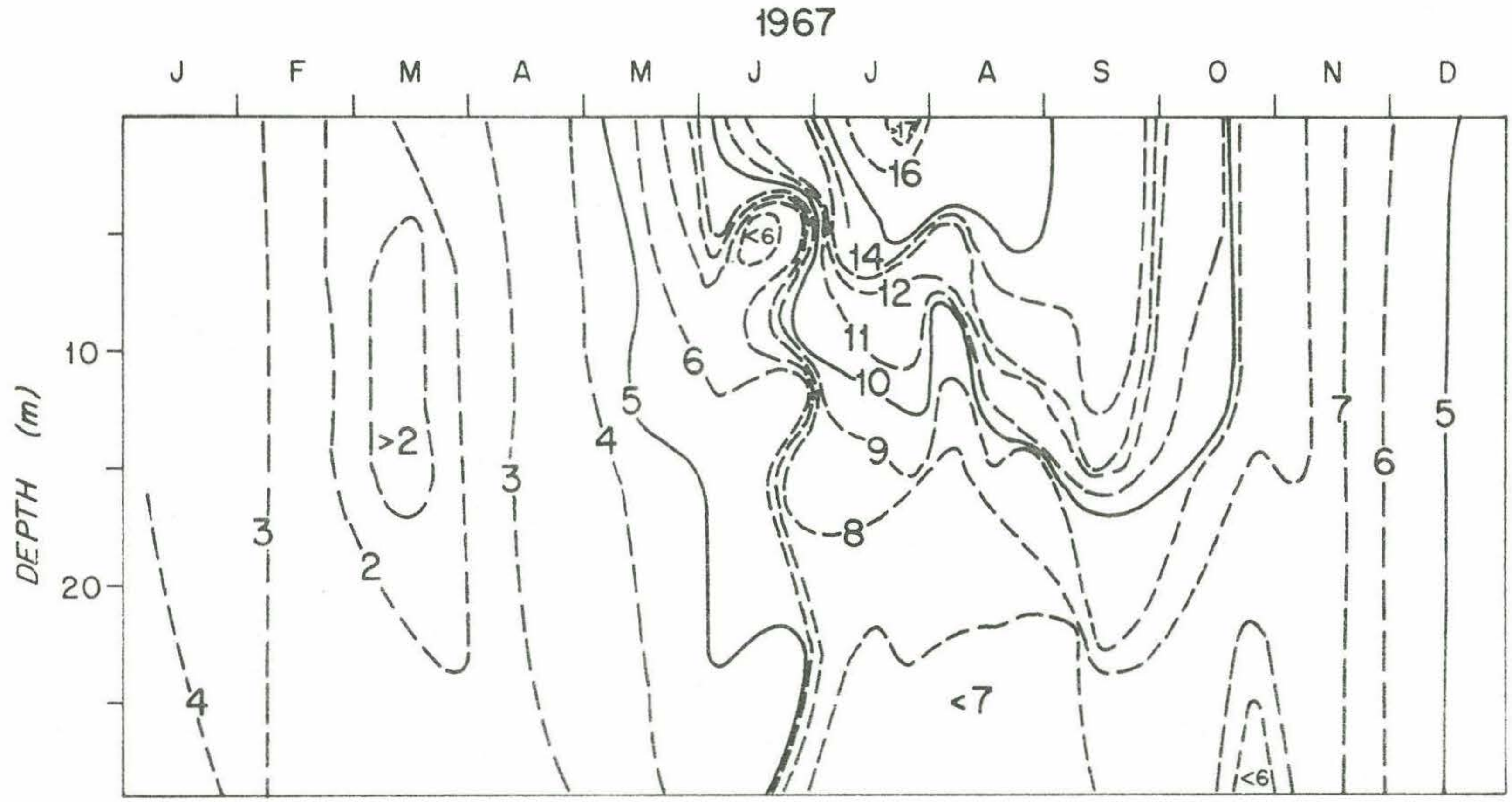


Figure 26: Profile of annual temperature cycle at Boston Lightship for 1967

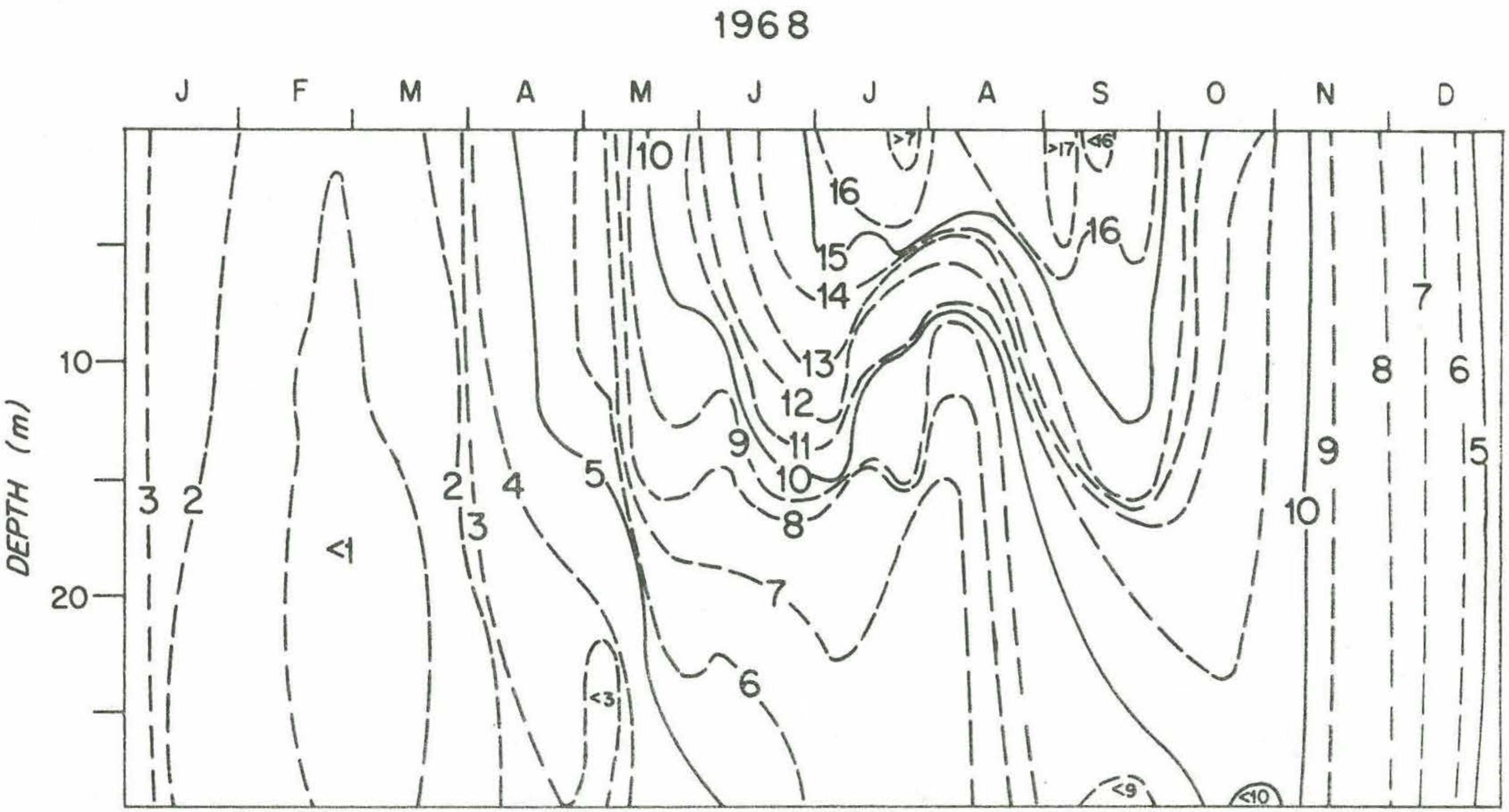


Figure 27: Profile of annual temperature cycle at Boston Lightship for 1968

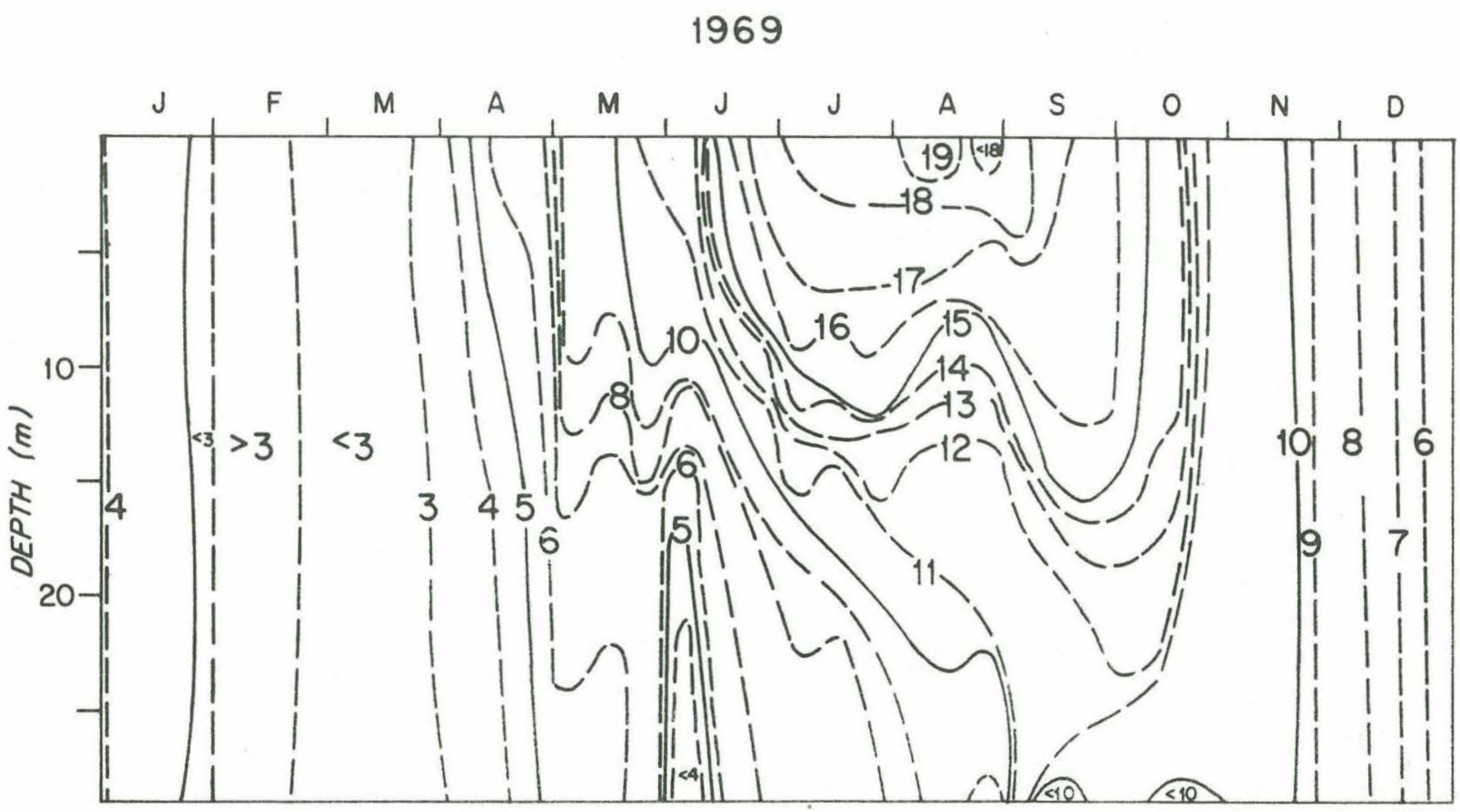


Figure 28: Profile of annual temperature cycle at Boston Lightship for 1969

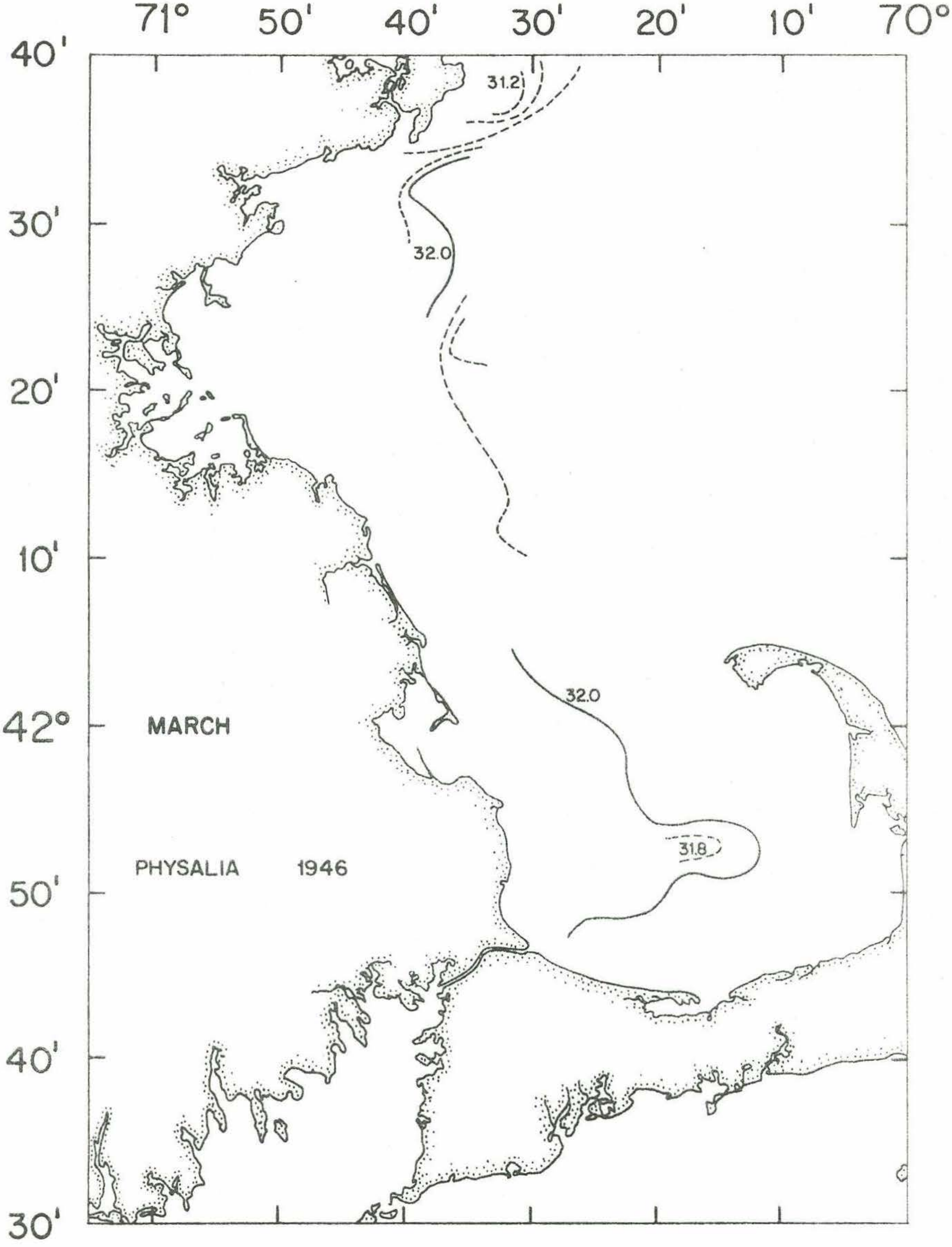


Figure 30: Surface salinity in March 1946

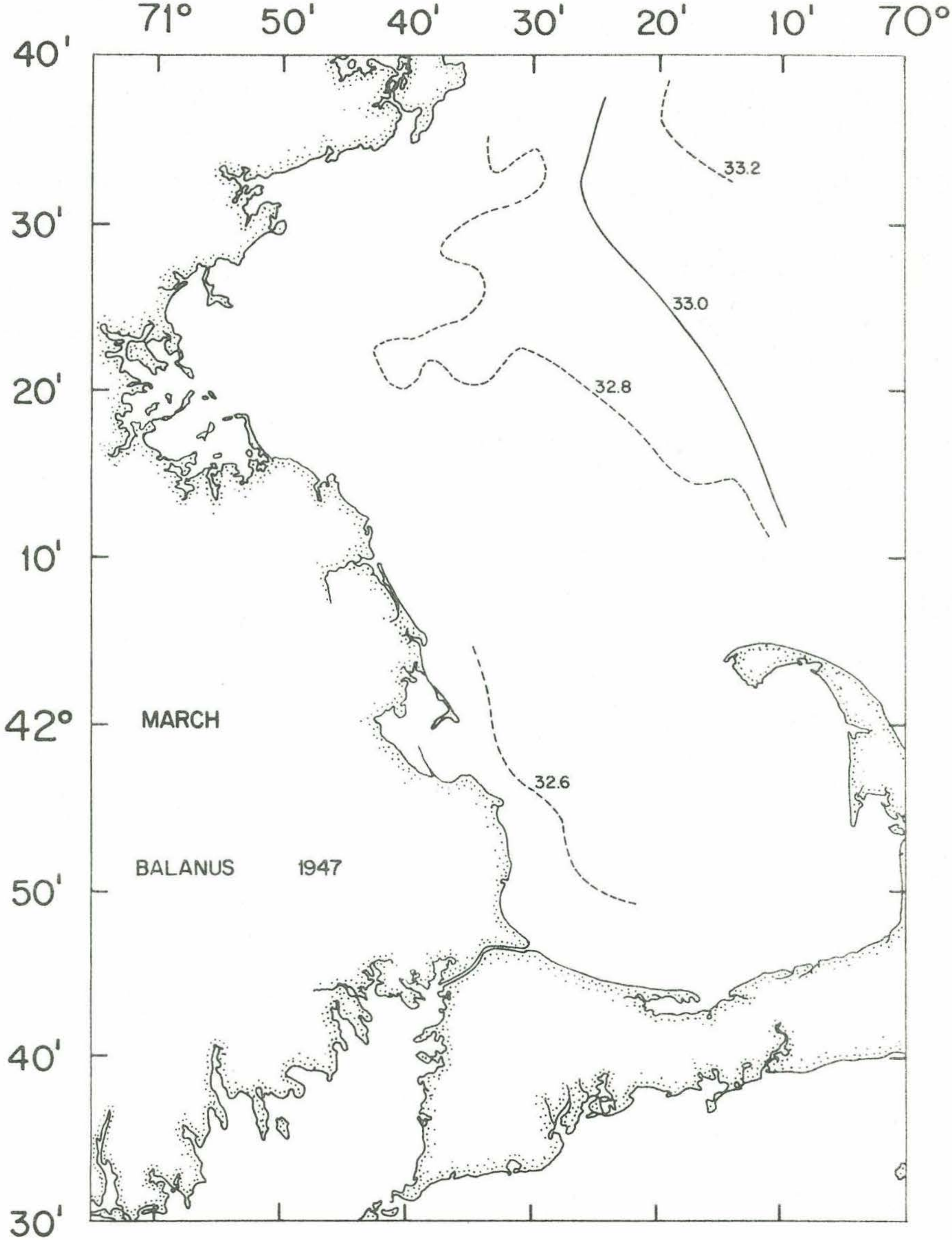


Figure 31: Surface salinity in March 1947

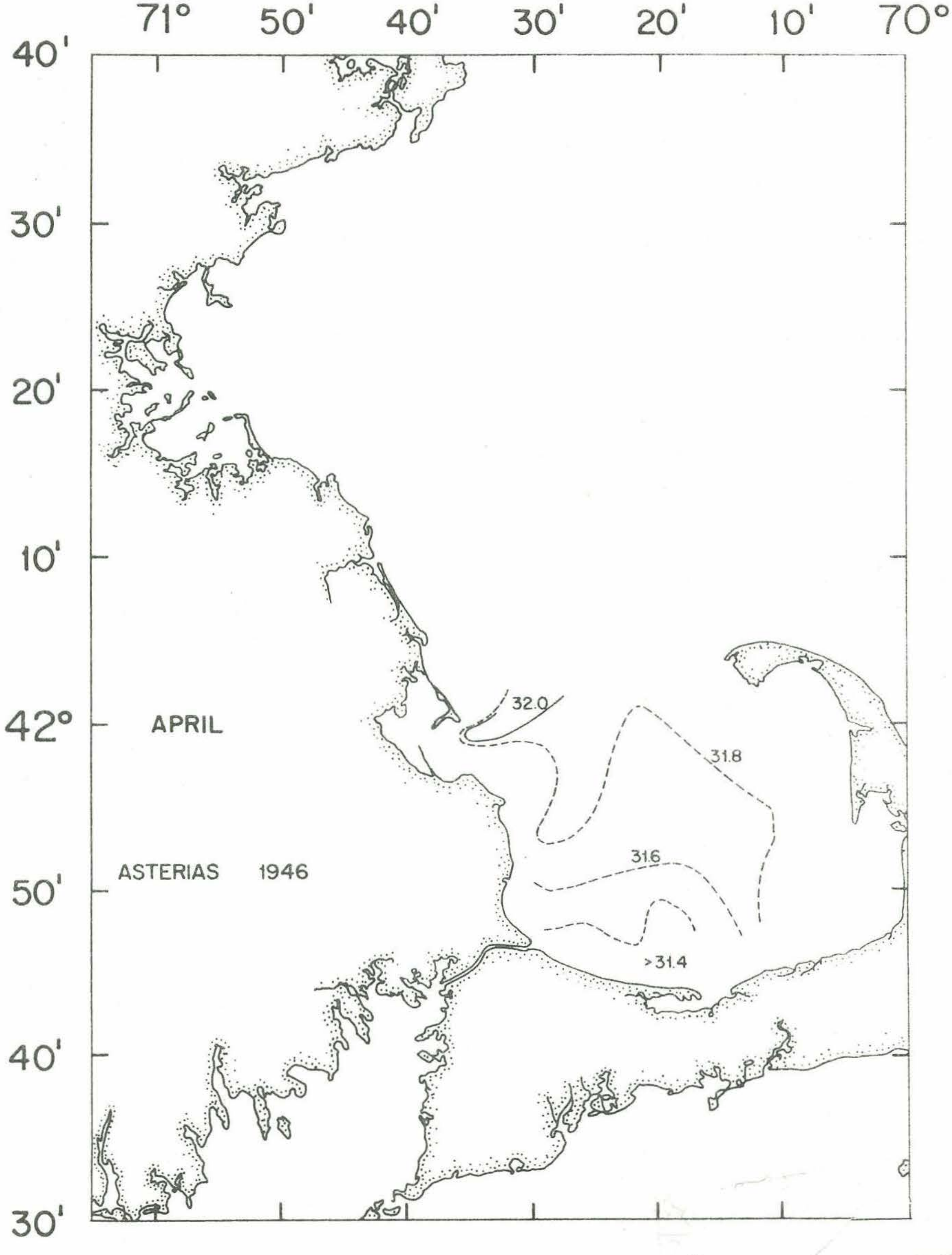


Figure 32: Surface salinity in April 1946 (Asterias)

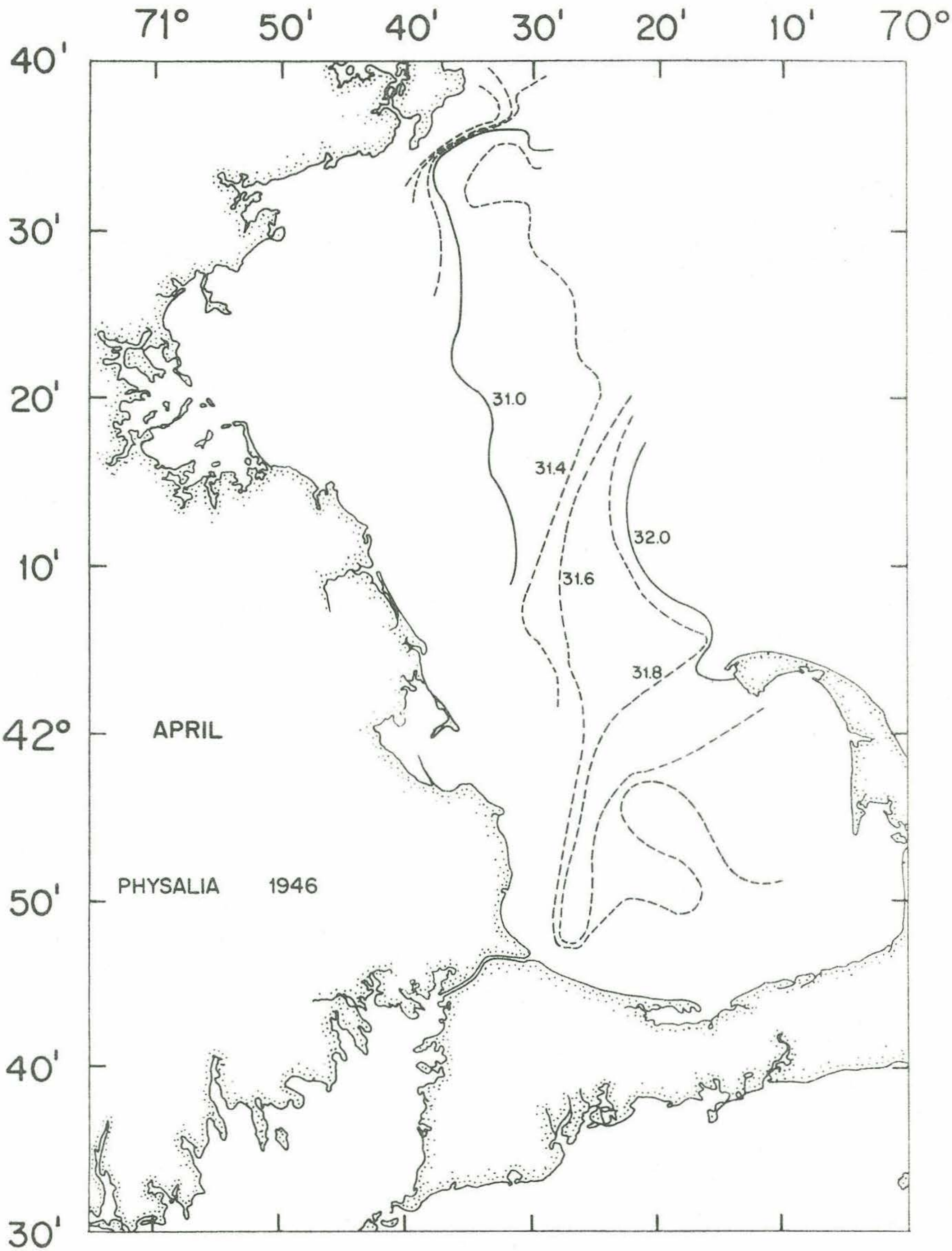


Figure 33: Surface salinity in April 1946 (Physalia)

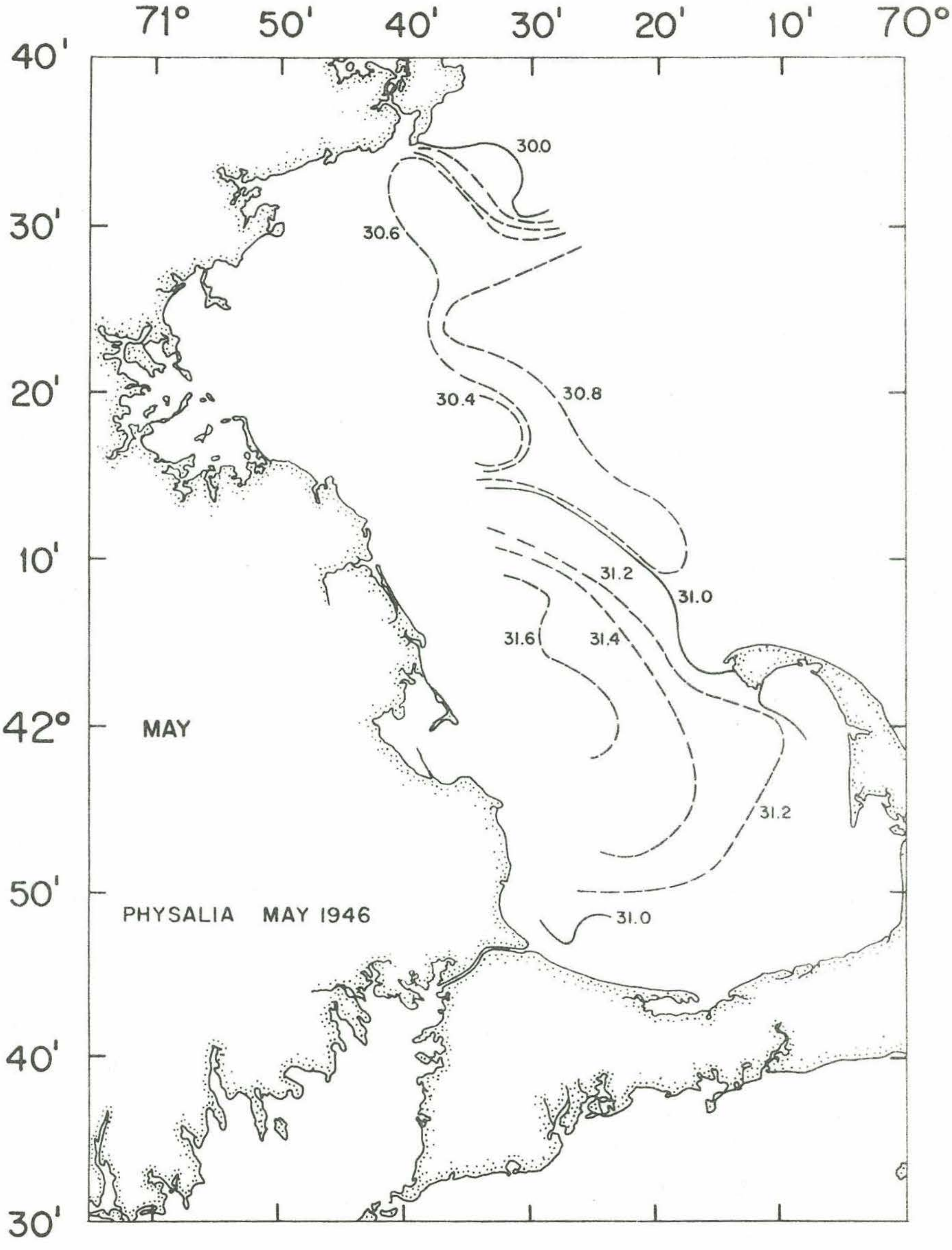


Figure 34: Surface salinity in May 1946

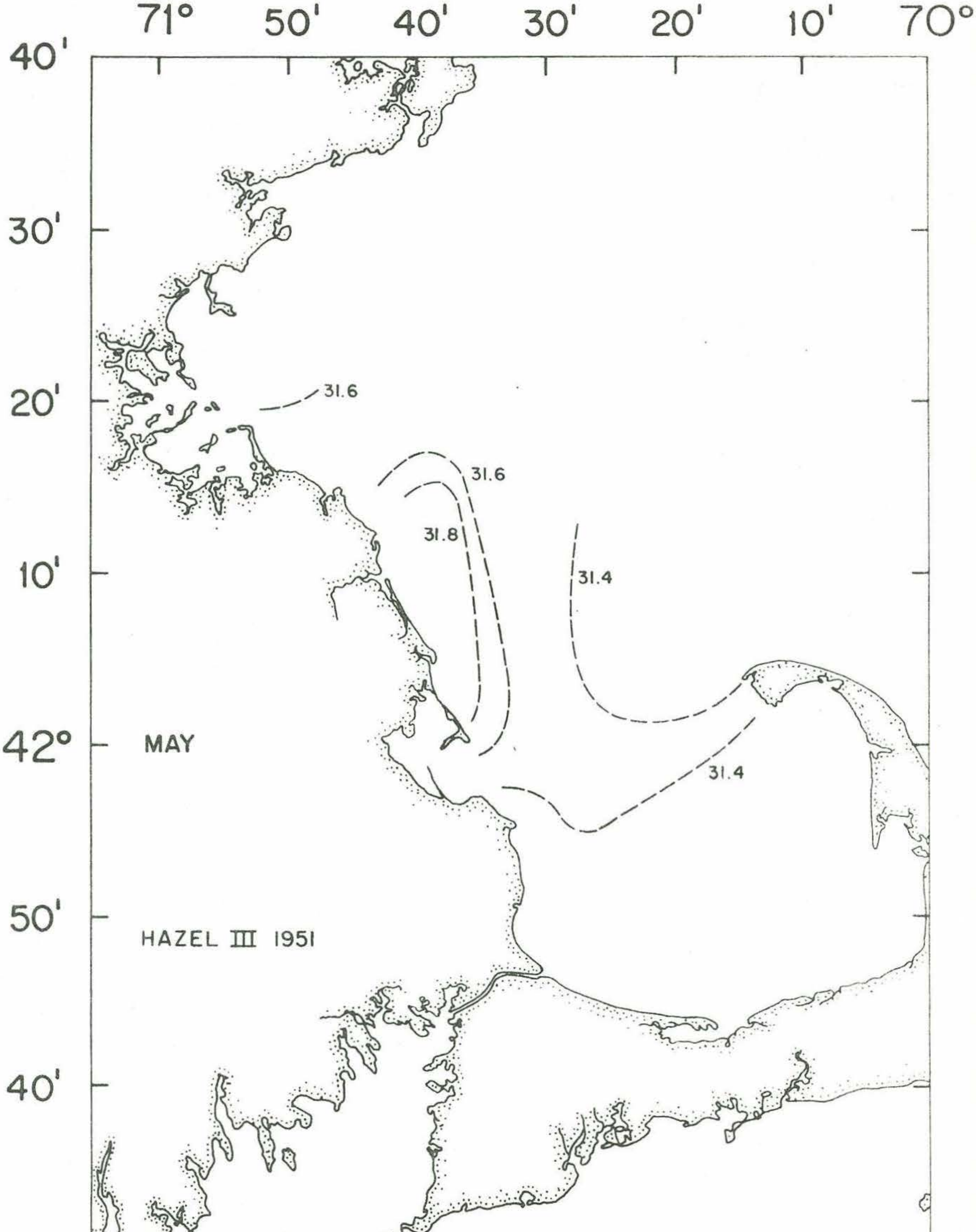


Figure 35: Surface salinity in May 1951

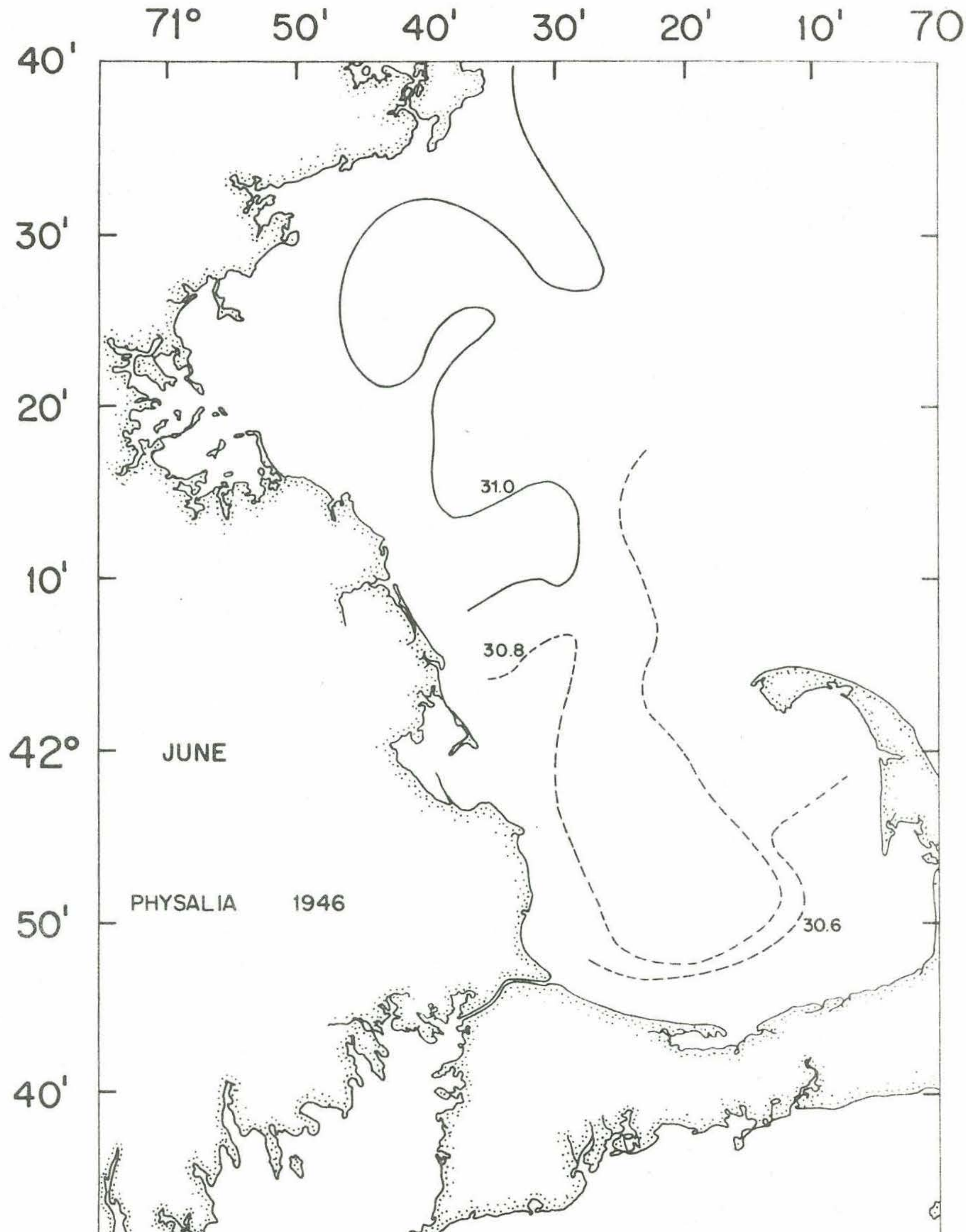


Figure 36: Surface salinity in June 1946

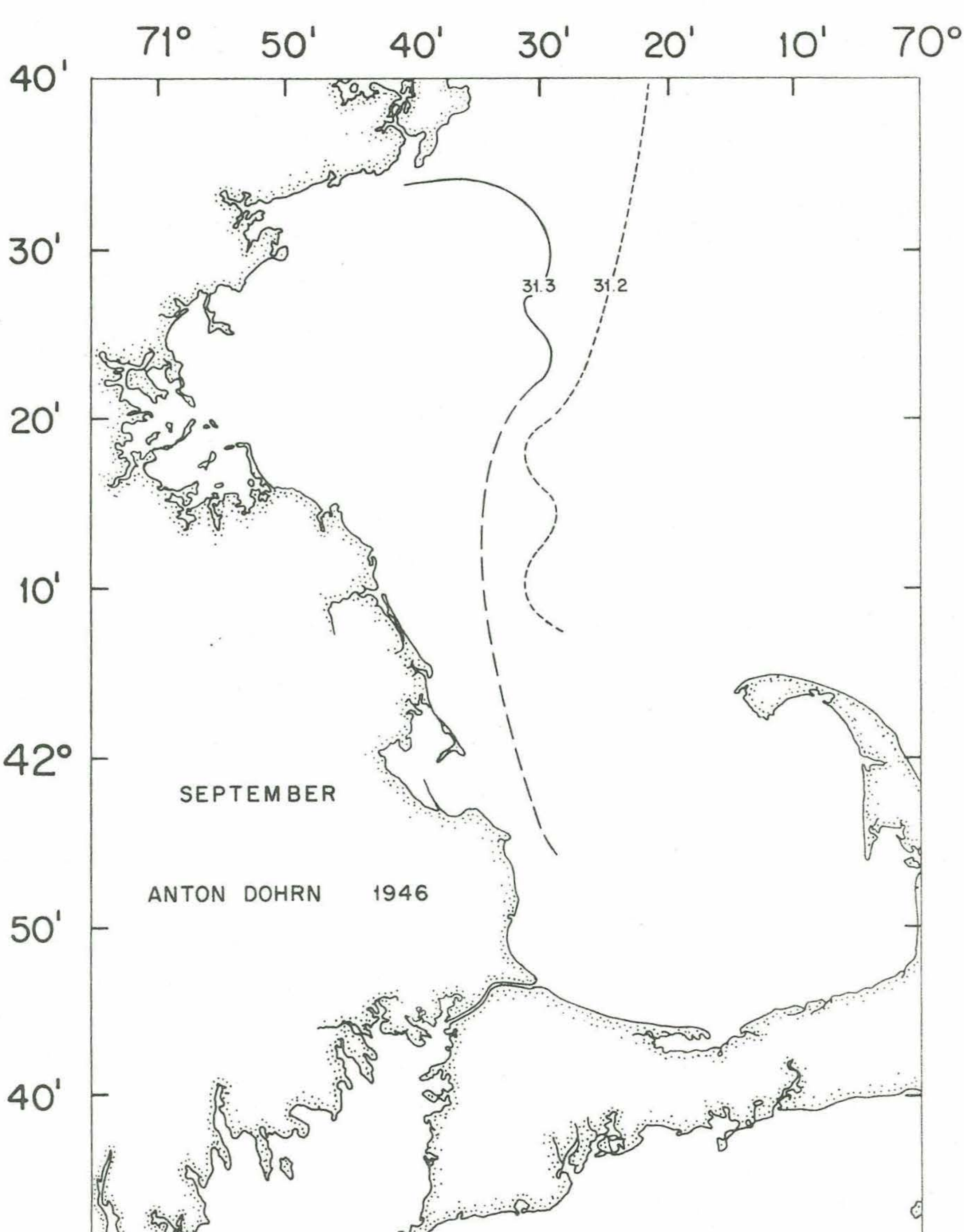


Figure 37: Surface salinity in September 1946

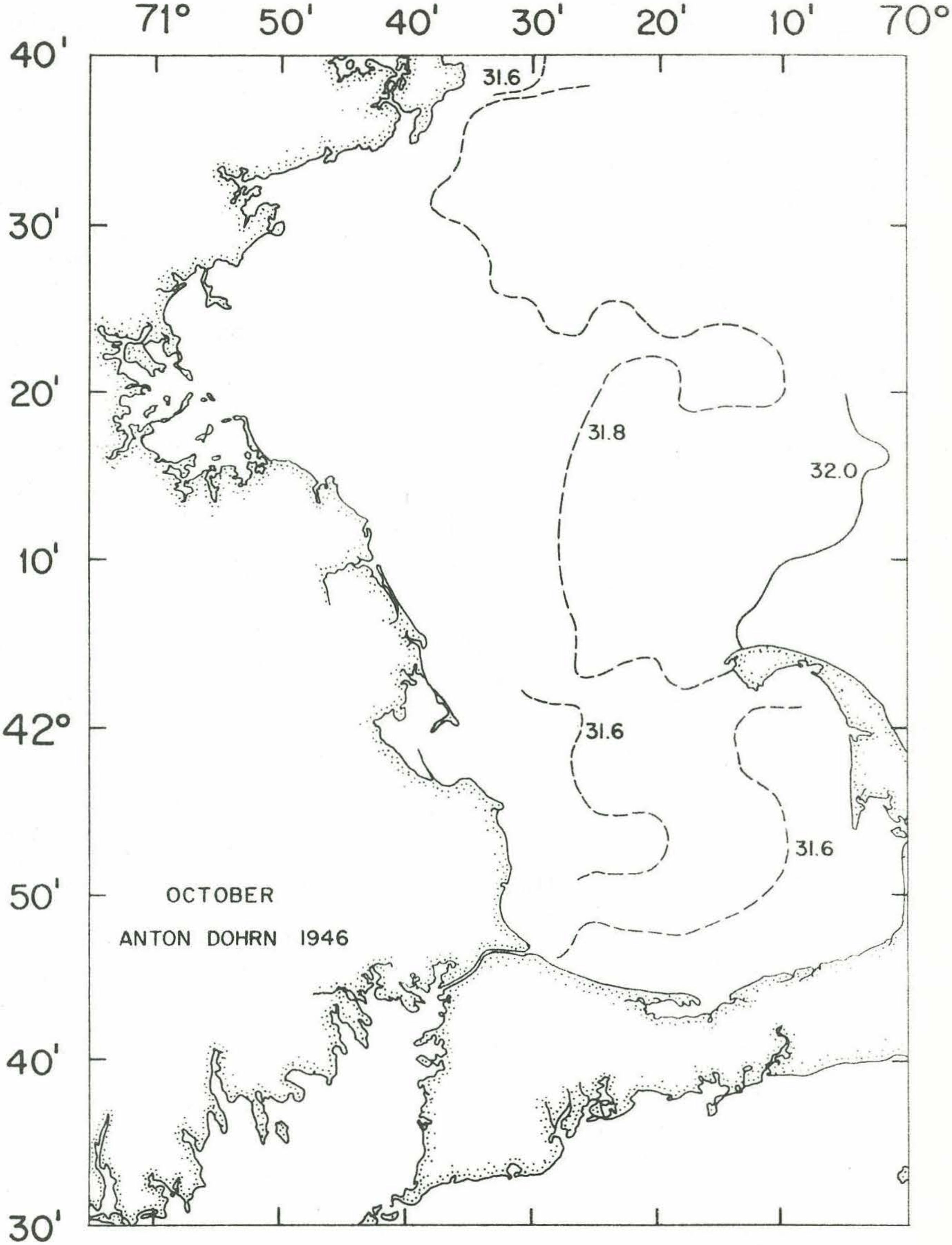


Figure 38: Surface salinity in October 1946

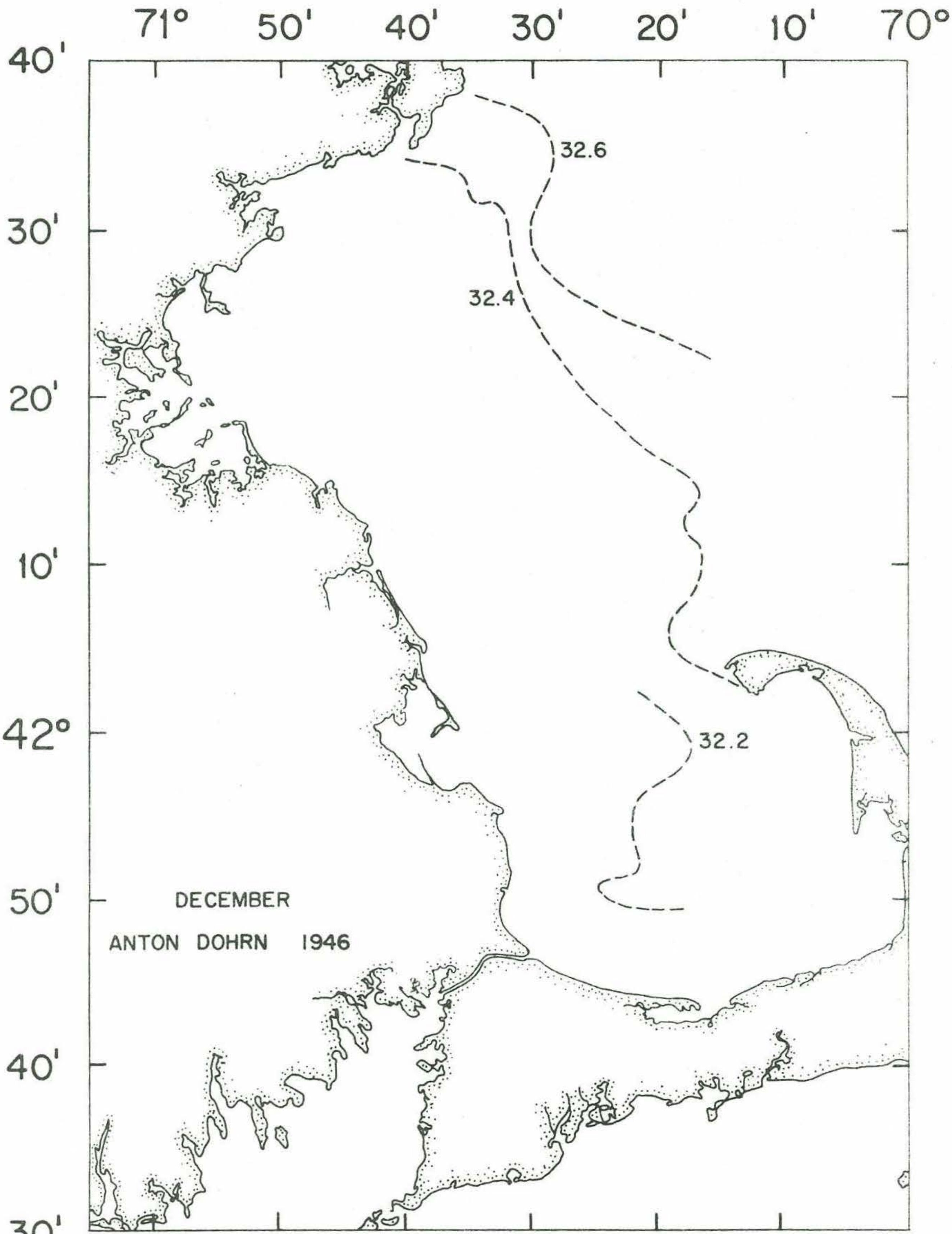


Figure 40: Surface salinity in early December 1946

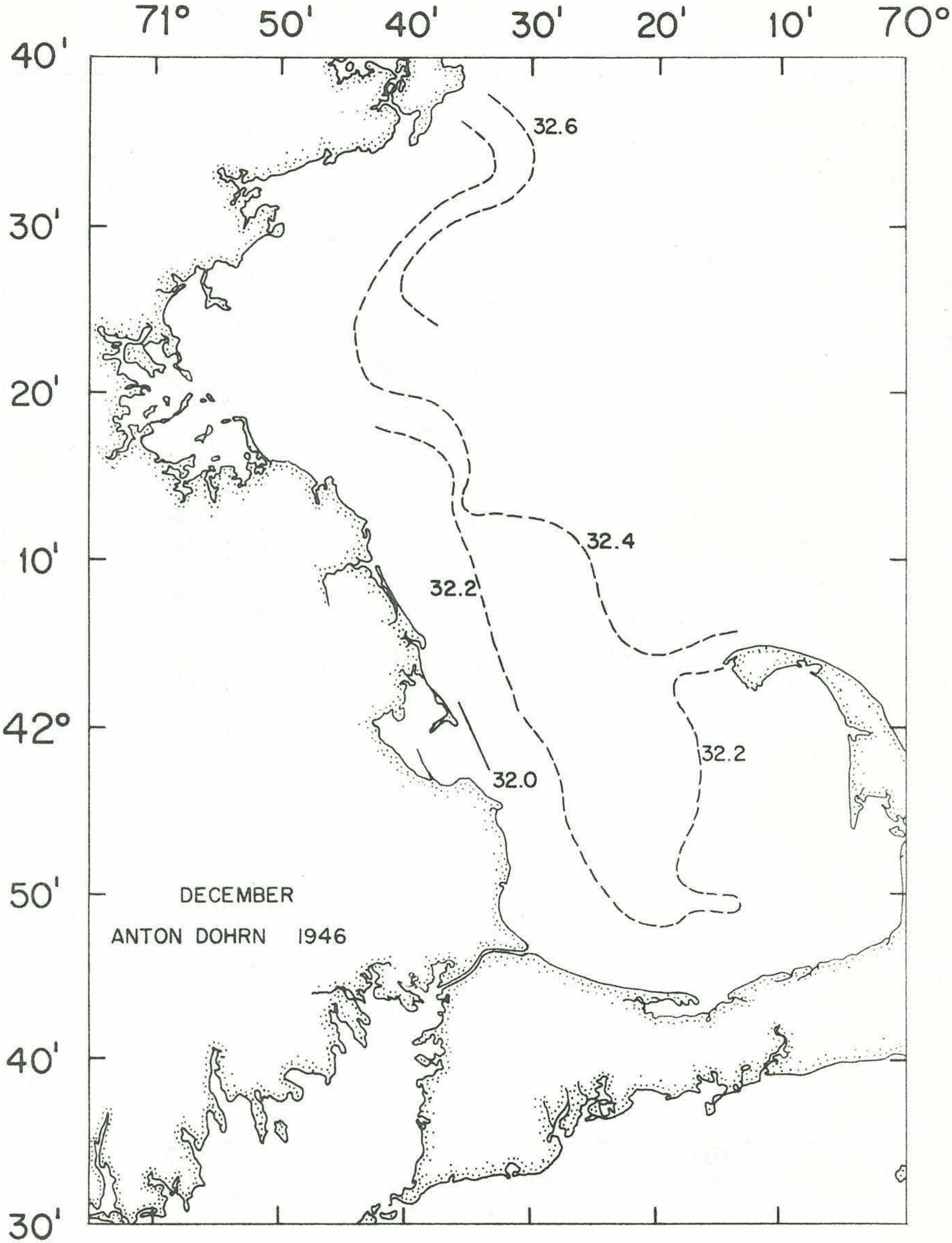


Figure 41: Surface salinity in mid-December 1946

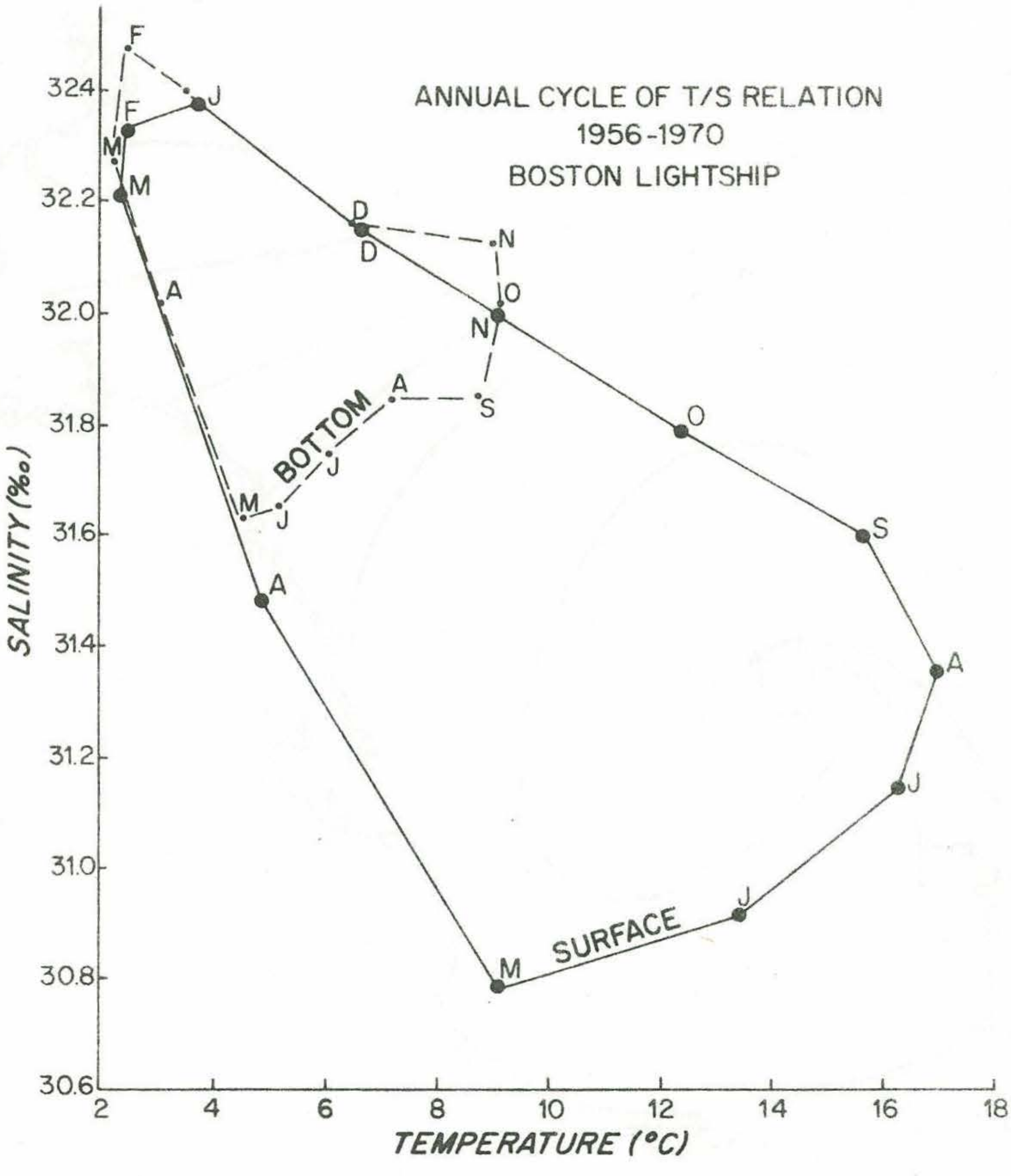


Figure 43: Annual cycle of T/S relation at Boston Lightship, 1956-1970

Table I. Sources of tidal current information for Massachusetts Bay

Prepared by Richard Boehmer of the Commonwealth of Massachusetts, Department of Natural Resources

YEAR	DATE	LAT.	LONG.	REFERENCE	DEPTH	METHOD	MAX. FLOOD	MAX. EBB
1855	Sept. 17	42°10'35"	70°16'11"	NOAA-NOS historical (Stellwagen)	surface	?	1.45kt., N73W true;	1.30kt., N73E true
	Sept. 21	42°02'08"	70°01'30"	" " "	surface	?	0.60kt., N74W true;	1.28kt., S27E true
	Oct. 16	42°13'07"	70°36'50"	" " "	surface	?	0.63kt., N89W true;	0.69kt., N24E true
	Oct. 17	42°00'29"	70°33'30"	" " "	surface	?	0.80kt., S12W true;	
	Oct. 18	42°06'32"	70°31'56"	" " "	surface	?	0.74kt., S75W true;	0.54kt., S86E true
1860	July 22-23	41°50'46"	70°30'24"	NOAA-NOS historical (Mitchell)	surface	meter	0.02kt., southerly;	0.72kt., northerly
					30 ft.	globes & line	0.11kt., 345°mag.;	0.62kt., northerly
	July 23-24	41°48'11"	70°31'25"	" " "	surface	meter	0.14kt., 122°mag.;	0.05kt., 226° mag.
					26 ft.	globes & line	0.21kt., 122°mag.;	0.14kt., 226° mag.
	July 24-25	41°46'26"	70°28'46"	" " "	surface	meter	0.05kt., 35°mag.;	0.14kt., 245° mag.
					26 ft.	globes & line	0.12kt., 35°mag.;	
1861	Aug. 18-19	0.5 mi W of Race Pt.		NOAA-NOS historical (Mitchell)	surface	?	1.0 kt., S.W.;	1.0 kt., N. & N.W.
	Aug. 21	2 mi E of MaryAnn Rks.		" " "	surface	?	0.2 kt., S.byE.or W.;	0.5 kt., (N.?)
1877	Sept. 27-28	42°28'15"	70°29'47"	NOAA-NOS historical (Platt)	20 ft.	loaded pole	0.52kt., S67W;	0.29kt., N14E
					5 fathoms	can & key	0.49kt., S81W;	0.31kt., N22E
					10 fathoms	can & keg	0.48kt., S74W;	0.33kt., N8E
					20 fathoms	can & 2 kegs	0.42kt., S78W;	0.28kt., N20E

YEAR	DATE	LAT.	LONG.	REFERENCE	DEPTH	METHOD	MAX. FLOOD	MAX. EBB
1887	Aug. 20-21	N of Race point		NOAA-NOS historical				
	Aug. 24-25							
1902	July 24	42°01'26"	70°13'08"	NOAA-NOS historical (Marindin)	surface	?	1.25kt., S41E;	0.96kt., N45W
	July 25, 29	42°00'54"	70°11'59"	" " "	surface	?	0.26kt., S58E;	0.62kt., N73W
	July 26, 30, 31	42°02'06"	70°14'08"	" " "	surface	?	1.20kt., S41E;	0.83kt., N45W
1913	Sept. 22-Dec. 26	42°20.4'	70°45.4'	USCGS Special Pub. 142 (Shureman)	surface	current pole	0.14kt., 260° true;	0.15kt., 84° true
1916	4 sta. in Plymouth Bay			Hawley	?	?	?	?
	2 sta. off Brant Rock							
1919	March-May	42°24.1'	70°23.8'	USCGS Special Pub. 230 (Haight)	surface	?	0.16kt., 243° true;	0.18kt., 63° true
1926-27	June-June	42°20.4'	70°45.4'	USCGS Special Pub. 230 (Haight)	surface	?	0.08kt., 267° true;	0.08kt., 88° true
1927	June 8-30	42°20.4'	70°45.4'	USCGS Special Pub. 142 (Shureman)	surface	?	0.06kt., 264° true;	0.10kt., 86-92° true
1942	Sept. 26-Oct. 31	0.5 mi W of Race Pt.		USN (Slooks)		?	?	?
1953	Oct. 20-21	41°43.6'	70°16.4'	NOAA-NOS historical (Paton)	7 ft.	pole	1.55kt., 192° true;	1.75 kt., 4° true
1959	June 5-9	42°25.7'	70°38.0'	NOAA-NOS historical (Wennermark)	15 ft.	Roberts	< 0.8kt., 254°;	< 0.5kt.,
					150 ft.	Roberts	< 0.5kt.,	< 0.5kt.,
					285 ft.	Roberts	< 0.5kt.,	< 0.5kt.,
	June 6-9	42°25.6'	70°35.0'	" " "	15 ft.	Roberts	< 1.0kt., 254°	< 1.0kt.,
					285 ft.	Roberts	< 0.5kt.,	< 0.5kt.,

YEAR	DATE	STATION	LAT.	LONG.	REFERENCE	DEPTH	METHOD	MODAL FLOOD	MODAL EBB	SPEED
1967	July 13-17	(T)	42°16.5'	70°24.9'	NOAA-ERL-229-POL7 (Halpern)	10.6 meters	meter	140°	15°	29.3 cm/sec
						25.8 meters	meter	230°	75°	15.3 cm/sec
						45.6 meters	meter	240°	100°	13.5 cm/sec
	July 24-28	(E)	42°16.2'	70°16.6'	" " " "	7.6 meters	meter	270°	65°	42.6 cm/sec
						15.2 meters	meter	280°	65°	36.1 cm/sec
						22.8 meters	meter	270°	75°	36.5 cm/sec
	Aug. 22-25	(A)	42°16.6'	70°08.5'	" " " "	10.6 meters	meter	300°	60°	29.0 cm/sec
						25.8 meters	meter	275°	130°	21.5 cm/sec
						45.6 meters	meter	290°	100°	17.8 cm/sec
1968	Oct. 6-18	(37)	42°20.0'	70°25.0'	NOAA-NOS recent files	15 feet	meter	rotary at about 1 knot		
1970	summer & fall		28 stations all over the Bay		Brad Butman (MIT-WHOI) John Schlee (USGS)	near bottom	meters			
1971	July 21-28	(71A)	42°27.5'	70°50.7'	NOAA-NOS recent files	10 feet	meter	rotary at about 0.5 knot		
	Aug. 24-31	(120)	42°19.6'	70°51.5'	NOAA-NOS recent files	10 feet	meter			
						35 feet	meter			
						60 feet	meter			
	Aug. 24-31	(121)	42°18.8'	70°51.6'	NOAA-NOS recent files	10 feet	meter			
						35 feet	meter			
	July 28-Aug. 12	(139)	42°22.1'	70°55.4'	NOAA-NOS recent files	10 feet	meter			
						25 feet	meter			
	July 7-22	(145)	42°24.1'	70°55.0'	" " " "	10 feet	meter			

YEAR	DATE	STATION	LAT.	LONG.	REFERENCE	DEPTH	METHOD	MODAL FLOOD	MODAL EBB	$\bar{X}$ SPEED
1971	July 7-22	(145)	42°24.1'	70°55.0'	NOAA-NOS recent files	45 feet	meter			
						60 feet	meter			
	July 7-22	(146)	42°25.8'	70°52.2'	" " " "	10 feet	meter			
						45 feet	meter			
						80 feet	meter			
	July 8-22	(147)	42°23.6'	70°51.2'	" " " "	10 feet	meter	250° true;	70° true;	0.68 kts.
						45 feet	meter	255° "	80° "	0.28 "
						70 feet	meter	260° "	85° "	0.15 "
	July 7-22	(148)	42°21.6'	70°52.0'	" " " "	10 feet	meter	240° "	110° "	0.60 "
						45 feet	meter	260° "	90° "	0.35 "
						60 feet	meter	250° "	70° "	0.26 "
	July 7-27	(149)	42°19.2'	70°50.2'	" " " "	10 feet	meter	-	110° "	0.74 "
						45 feet	meter	300° "	110° "	0.22 "
	July 8-27	(150)	42°23.2'	70°44.4'	" " " "	10 feet	meter	-	140° "	0.73 "
						45 feet	meter	240° "	130° "	0.35 "
						75 feet	meter	230° "	130° "	0.22 "
						100 feet	meter	230° "	110° "	0.20 "
	July 8-27	(151)	42°18.3'	70°44.6'	" " " "	10 feet	meter	230° "	120° "	0.68 "
						45 feet	meter	250° "	115° "	0.23 "
						75 feet	meter	250° "	90° "	0.20 "

YEAR	DATE	STATION	LAT.	LONG.	REFERENCE	DEPTH	METHOD
1972	Sept. 22-Oct. 2	(900A)	42°21.3'	70°47.1'	NOAA-NOS recent files	10 feet	meter
						65 feet	meter
	Oct. 2-Oct. 11	(900B)	42°21.3'	70°47.5'	" " " "	10 feet	meter
						45 feet	meter
						65 feet	meter
	Sept. 5-13	(960)	42°24.6'	70°54.1'	" " " "	15 feet	meter
						25 feet	meter
						65 feet	meter
	Sept. 5-12	(961)	42°25.2'	70°53.6'	" " " "	15 feet	meter
						25 feet	meter

1972 Seven (7) other (1, 5, 9, 13, 14, 16, 18) NOAA-NOS stations at various depths; data not worked up.

1970-present Butman-Schlee Many other stations, bottom current metering and possibly other depths.

1973 TIDAL CURRENT TABLES (NOAA-NOS reference cards are more helpful)

	LOCATION	LAT.	LONG.	REFERENCE	MAX. FLOOD	$\bar{X}$ SPEED	MAX. EBB	$\bar{X}$ SPEED
410	Gloucester Harbor entrance	42°34.9'	70°40.5'	Ellerbe, Oct. 1955	340° true,	0.3 knots;	195° true,	0.3 knots
420	Marblehead Channel outercoast	42°30'	70°49'		285° "	0.4 "	105° "	0.4 "
425	Nahant, off East Point	42°25'	70°54'		235° "	0.8 "	85° "	0.7 "
430	Lynn Harbor entrance	42°25'	70°57'		325° "	0.5 "	170° "	0.5 "
435	Winthrop Beach	42°23'	70°57'	Finnegan, 1929	195° "	0.4 "	94° "	0.2 "
440	Stellwagen Bank	42°24'	70°24'	U.S.S. Easthampton, 1919	233° "	0.2 "	53° "	0.2 "
445	Boston Lightship	42°20'	70°45'	1926-1927	267° "	0.1 "	88° "	0.1 "
450	North Channel	42°21'	70°56'	Dec. 1953	198° "	1.2 "	25° "	1.4 "
455	Hypocrite Channel	42°21'	70°54'		255° "	1.2 "	70° "	1.0 "
460	Nantasket Roads	42°19.2'	70°53.3'	July & August 1926	260° "	1.4 "	85° "	1.5 "
655	7 nm. N. Race Point	42°11'	70°16'	Stellwagen, Sept. 1855	290° "	1.5 "		1.5 "
660	1 nm. NW Race Point	42°05'	70°15'	Platt, Aug. 1877	226° "	1.0 "	61° "	0.9 "
665	Provincetown Harbor	42°03'	70°10'		315° "	0.6 "	135° "	0.4 "
670	Wellfleet Harbor	41°54'	70°03'		20° "	0.7 "	200° "	0.5 "
675	Barnstable Harbor	41°44'	70°16'	Paton, Oct. 1953	192° "	1.2 "	4° "	1.4 "
690	1 nm. E. Ellisville Harbor	41°51'	70°30'		200° "	0.3 "	20° "	0.3 "
695	Manomet Point	41°56'	70°32'		155° "	1.1 "	10° "	0.9 "
700	1 nm. E. Gurnet Point	42°00'	70°35'		250° "	1.4 "		1.0 "
710	1 nm. E. Farnham Rock	42°06'	70°35'		180° "	1.1 "	10° "	0.9 "

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REVIEW OF THE PHYSICAL OCEANOGRAPHY OF MASSACHUSETTS BAY by Dean F. Bumpus. 157 pages. February 1974. National Marine Fisheries Service contract #03-3-043-40.

A description of the temperature-salinity cycle and the current system of Massachusetts Bay are described, supported by an annotated bibliography.

1. Ocean Temperatures
2. Salinity
3. Ocean Currents
4. Massachusetts Bay

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16. Abstracts

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2. Salinity
3. Ocean Currents
4. Massachusetts Bay

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17c. COSATI Field/Group

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